Volume 8, Number 4
July–August 2000

ISSN: 0869-5938

STRATIGRAPHY AND GEOLOGICAL CORRELATION

English Translation of *Stratigrafiya. Geologicheskaya Korrelyatsiya*

Editor-in-Chief
Boris S. Sokolov

http://www.maik.rssi.ru

Journal of the Fundamental and Applied Aspects of Stratigraphy and the Correlation of Geologic Events and Processes in Time and Space

МАИК "НАУКА/INTERPERIODICA" PUBLISHING

Stratigraphy and Geological Correlation

(Stratigrafiya. Geologicheskaya Korrelyatsiya)

ISSN: 0869-5938

Editor-in-Chief
Boris S. Sokolov

Member of the Russian Academy of Sciences,
Counsellor of the Presidium of the Russian Academy of Sciences (RAS)
Address for correspondence:
Staromonetnyi per. 22, Moscow, 109180 Russia
Phones: 7 (095) 951-2164; Fax: 7 (095) 233-5590.

Deputy Editor-in-Chief
Mikhail A. Semikhatov
Member of the Russian Academy of Sciences
Head of Laboratory, Geological Institute, RAS
E-mail: semikhatov@ginran.msk.su

Assistant Editor
Aleksei B. Herman
Senior Scientist,
Geological Institute, RAS
E-mail: herman@ginran.msk.su

EDITORIAL BOARD

Mikhail A. Akhmet'ev
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
akhmetev@ginran.msk.su

Aleksandr S. Alekseev
Professor, Dr.Sci. (Geol.–Min.),
Department of Paleontology,
Moscow State University
aaleks@geol.msu.ru

Mikhail N. Alekseev
Dr. Sci. (Geol.–Min.),
Chief Scientist, Geological Institute, RAS
alekseev@ginran.msk.su

Ivan A. Basov
Dr. Sci. (Geol.–Min.), Laboratory Chief,
Institute of the Lithosphere, RAS
basov@ilsan.msk.ru

Michael G. Basset
Professor, National Museum of Wales,
Cardiff, UK

William A. Berggren
Professor, Department of Geology and Geophysics,
Woods Hole Oceanographic Institute, USA

Elena V. Bibikova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Vernadsky Institute of Geochemistry
and Analytical Chemistry, RAS
sergei@bibikov.genebee.msu.su

Nikita A. Bogdanov
Corresponding Member of
RAS, Director, Institute of the Lithosphere, RAS
bogdanov@ilsan.msk.ru

Kiyotaka Chinzei
Professor, Institute of Geology,
University of Tokyo,
Tokyo, Japan

Nikolai M. Chumakov
Dr. Sci. (Geol.–Min.),
Chief Scientist, Geological Institute, RAS
chumakov@ginran.msk.su

Yurii B. Gladenkov
Dr. Sci. (Geol.–Min.),
Head of Laboratory, Geological Institute, RAS
gladenkov@ginran.msk.su

Mikhail A. Fedonkin
Corresponding Member of RAS, Laboratory Chief,
Paleontological Institute, RAS
mfedon@paleo.ru

Dmitrii L. Kaljo
Professor, Institute of Geology, Tallinn, Estonia

Kirilla L. Kuznetsova
Dr. Sci. (Geol.–Min.), Chief Scientist,
Geological Institute, RAS
kuznetsova@ginran.msk.ru

Victor E. Khain
Member of RAS, Chief Scientist,
Institute of the Lithosphere, RAS

Evgenii E. Musatov
Dr. Sci. (Geol.–Min.), Chief of St. Petersburg
Division, Institute of the Lithosphere, RAS
musatov@gocean.spl.su

Lidiya A. Nevesskaya
Dr. Sci. (Biol.), Laboratory Chief,
Institute of Paleontology, RAS
lenin33@paleo.ru

Aleksandr G. Ponomarenko
Dr. Sci. (Biol.), Chief Scientist,
Institute of Paleontology, RAS
vtopor@paleo.ru

Jurgen Remane
Professor, Institute de Géologie,
Université de Neuchâtel, Switzerland

Aleksei Yu. Rozanov
Corresponding Member of RAS,
Director, Institute of Paleontology, RAS
aroza@paleo.ru

Boris A. Sokolov
Corresponding Member of RAS, Professor, Dean,
Faculty of Geology, Moscow State University
mfedon@paleo.ru

Otto Walliser
Professor, Göttingen University, Göttingen,
Germany

Sun Weigo
Professor, Nanjing Institute of Geology
and Paleontology, Academia Sinica, China

Victor A. Zakharov
Dr. Sci. (Geol.–Min.), Head of Laboratory, Institute
of Geology, Geophysics, and Mineralogy, Siberian
Division, RAS, Novosibirsk

Aleksandr I. Zhamoida
Corresponding Member of RAS,
Russian Geological Institute, St. Petersburg

Staff Editor Tamara V. Trishkina

Editor of the English Translation Anatolii Ya. Sharas'kin, Dr. Sci. (Geol.–Min.)

SCOPE

Stratigraphy and Geological Correlation (*Stratigrafiya. Geologicheskaya Korrelyatsiya*) is the only journal in the world designed to provide comprehensive coverage of the fundamental and applied aspects of stratigraphy and the correlation of geological events and processes in time and space. Articles are based on the results of multidisciplinary research and are directed toward researchers, university professors, students, and geologists interested in understanding stratigraphy and the chronological features of the world's geological record.

Stratigraphy and Geological Correlation is abstracted and/or indexed in *Petroleum Abstracts*, *Research Alert*, *SciSearch*, *Current Contents* (*Physical, Chemical*, and *Earth Sciences*) and *World Translations Index*.

SUBSCRIPTION OFFICE
INTERPERIODICA
P.O. BOX 1831, BIRMINGHAM, AL 35201-1831 USA
PHONE: (800) 633-4931; (205) 995-1567 (outside US and Canada)
FAX: (205) 995-1588

PUBLISHER
INTERNATIONAL ACADEMIC PUBLISHING
COMPANY "NAUKA/INTERPERIODICA"
PROFSOYUZNAYA UL. 90, MOSCOW, 117864 RUSSIA
PHONE: 7 (095) 336-1600; FAX: 7 (095) 336-0666
E-mail: compmg@maik.rssi.ru
Web Site: http://www.maik.rssi.ru

SUBSCRIPTION PRICES (2000, Volume 8, 6 issues)
US $980.00 (North America), $1125.00 (elsewhere). A 5% discount is given on 2-year orders. Subscriptions may be entered at any time. Orders may be placed at agencies or directly. There is a 5% discount to all subscription agencies. Cancellations not allowed except for duplicate payment. Prepayment required. Advance payment required in US$/US bank. MasterCard/Visa accepted. Make checks payable to *Stratigraphy and Geological Correlation* or Interperiodica.

Stratigraphy and Geological Correlation (ISSN: 0869-5938) is published bimonthly for US $980.00 (North America), outside North America for $1125.00 per year by MAIK "Nauka/Interperiodica", 5724 Hwy. 280 East, Birmingham, Alabama 35242-5724 USA. Periodical postage paid at Birmingham, Alabama, and additional mailing offices. POSTMASTER: Send address changes to *Stratigraphy and Geological Correlation*, P.O. Box 1831, Birmingham, Alabama 35201 USA.

The journal was founded in 1993.

Original Russian Edition Copyright © 2000 by the Russian Academy of Sciences
and Division of Geology, Geophysics, Geochemistry, and Mining Sciences, RAS.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).
Printed in the USA by Pleiades Publishing, Inc.

Contents

Vol. 8, No. 4, 2000

Simultaneous English language translation of the journal is available from MAIK "Nauka/Interperiodica" (Russia).
Stratigraphy and Geological Correlation ISSN 0869-5938.

Stratigraphy of the Kostomuksha Belt in Karelia (Upper Archean) as Inferred from Geochronological, Geochemical, and Isotopic Data
S. B. Lobach-Zhuchenko, N. A. Arestova, R. I. Mil'kevich, O. A. Levchenkov, and S. A. Sergeev 319

Pre-Ediacarian Fauna from Timan (Annelidomorphs of the Late Riphean)
M. B. Gnilovskaya, A. F. Veis, Yu. R. Bekker, V. G. Olovyanishnikov, and M. E. Raaben 327

Correlated Ammonoid Zonation in Ladinian Deposits of the Boreal Realm
A. G. Konstantinov 353

Middle–Late Triassic Radiolarians from the Dzhugadzhak Section (the Omolon Massif)
N. Yu. Bragin and A. Yu. Egorov 362

On the Regional Konkian Stage (Middle Miocene) in the Eastern Paratethys
L. B. Il'ina 372

Stage Subdivision of the Paleocene
D. P. Naidin and V. N. Ben'yamovskii 378

The Problem of the Miocene–Pliocene Boundary in the Euxinian Region
I. S. Chumakov† 396

Stratigraphy and Paleogeography of Marine Holocene (the Primor'e Shelf)
N. N. Kuz'mina and E. E. Taldenkova 405

Chronicle

Third Interdepartmental Regional Stratigraphic Meeting on the Lower Precambrian of Karelia and the Kola Peninsula
V. Z. Negrutsa, K. I. Heiskanen, T. F. Negrutsa, and V. I. Robonen 419

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 319–326. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 3–10.
Original Russian Text Copyright © 2000 by Lobach-Zhuchenko, Arestova, Mil'kevich, Levchenkov, Sergeev.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Stratigraphy of the Kostomuksha Belt in Karelia (Upper Archean) as Inferred from Geochronological, Geochemical, and Isotopic Data

S. B. Lobach-Zhuchenko, N. A. Arestova, R. I. Mil'kevich, O. A. Levchenkov, and S. A. Sergeev

Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, nab. Makarova 2, St. Petersburg, 199034 Russia

Received July 13, 1998; in final form, December 14, 1998

Abstract—A new version of stratigraphic scheme for the Kostomuksha greenstone belt in Karelia is suggested on the basis of lithological, geochemical, and isotopic data obtained for ultramafic, mafic, and acidic volcanic rocks of the Kontokki Group and for different rock varieties of the Gimola Group. Geochemical characteristics and results of Sm–Nd isotopic dating showed that basic volcanics of the Niemijarvi and Ruvinvaara formations are coeval, but older than the acidic volcanic rocks. Basal conglomerates and metasediments of the Gimola Group rest on the latter. According to isotopic and geochemical parameters, parental magmas of basalts in the lower part of the section are of the contaminated type and have been generated in environments of continental rifting. Lithological and geochemical analysis also demonstrated that some ultramafic schists of the Gimola Group correspond to peridotitic komatiites similar to those from the underlying Kontokki Group. Accordingly, episodes of ultrabasic magmatism typical of the latter continued during the deposition of terrigenous ferruginous–siliceous sediments of the Gimola Group. The estimated formation time is 2808 ± 95 Ma (this work) or 2843 ± 39 Ma (Puchtel *et al.*, 1997) for the lower mafic part of the section, and 2795 ± 10 Ma (this work) or 2795 ± 29 Ma (Samsonov *et al.*, 1995) for acidic volcanics. The time range of metasediments in the Gimola Group is limited by the date of 2795 ± 10 Ma characterizing the underlying acidic volcanics, which presumably constituted a part of provenance for siliciclastic metasediments. The upper age limit is defined by the date of 2707 ± 31 Ma obtained for plagoigranite porphyry intruding the schists.

Key words: *Stratigraphy, Archean, Karelia, geochronology, geochemistry, Nd isotope composition.*

INTRODUCTION

New data on regional geology and isotopic geochronology persistently change stratigraphic schemes of concrete structures. To a great extent, this concerns sections of the Archean greenstone belts. Almost all these belts are of a complex tectonic structure and represent accretionary, or even collision-accretionary orogens. A considerable degree of their metamorphism eliminates original lithologic characteristics and creates a fine metamorphic banding of the rocks, which is hardly distinguishable from the graded bedding.

According to the Precambrian stratigraphic scale of the USSR accepted in 1990, the Upper Precambrian of Karelia was divided into the Hautavaara, Kontokki, and Gimola groups (Semikhatov *et al.*, 1991). The latter two groups were distinguished in the Kostomuksha belt, where the section is complete and accepted as the type one.

The Kostomuksha greenstone belt is located in the northwest of the Karelian granite–greenstone province (Fig. 1). Geology of the belt was studied for a long time (Chernov, 1959; Lazarev and Kozhevnikov, 1973; Gor'kovets and Raevskaya, 1981; Gor'kovets *et al.*, 1981; Kozhevnikov, 1982). Complex tectonic patterns of the belt gave rise to a variable interpretation of rock succession and, consequently, to different stratigraphic schemes. In the scheme that deserved a widest recognition (Gor'kovets *et al.*, 1981), the succession of supracrustal rocks was accepted as described below (Fig. 2, column I). The plagiogranite basement with local weathering crusts is overlain by volcanogenic–sedimentary deposits (*Zelenokamennye poyasa...*, 1988). These terrigenous rocks underlie volcanics of the Kontokki Group divided into three formations. The lower Niemijarvi Formation is composed of basalts intercalated with isolated komatiite interlayers. The middle Shurlovaara Formation includes acidic volcanics and volcanogenic–sedimentary deposits. The upper Ruvinvaara formation consists of komatiites and basalts (Fig. 2, column I). The total thickness of volcanic rocks in the Kontokki Group is about 5 km. This group is overlain by basal conglomerates of the Gimola Group predominantly terrigenous. The lower terrigenous formation of the Gimola group includes beds of ferruginous quartzite and carbonaceous schist. The upper part of the group is represented by mica schists.

Lazarev and Kozhevnikov, who studied in detail the tectonic history of the region, suggested their own

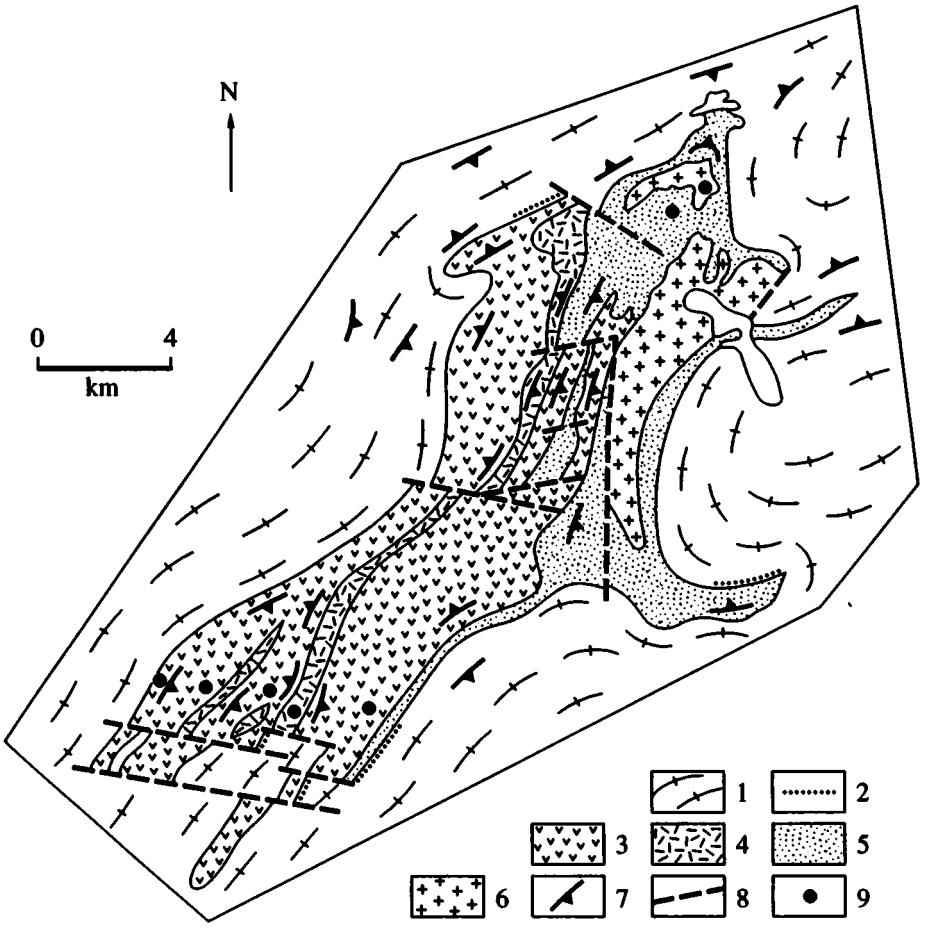


Fig. 1. Geological scheme of the Kostomuksha greenstone belt: (1) plagiogranite and migmatite; (2) sillimanite-quartz schist; (3) basalt–komatiite association of the Kontokki Group (Niemijarvi and Ruvinvaara formations); (4) acidic volcanics of the Kontokki Group (Shurlovaara Formation); (5) terrigenous metasediments of the Gimola Group; (6) microcline granite; (7) rock attitude; (8) tectonic boundary; (9) sampling site.

interpretation of the stratigraphic succession in the Kostomuksha belt (see in Kozhevnikov, 1982). This version is illustrated in Fig. 2 (column II).

Finally, isotopic–geochemical characteristics and new geochronological data allowed Puchtel *et al.* (1997) to present the third version of the Lopian rock succession in the Kostomuksha belt that was incompatible with the scheme accepted in the general stratigraphic scale. According to this version, mafic rocks of the Kontokki Group (Niemijarvi and Ruvinvaara formations in nomenclature of Gor'kovets *et al.*) are coeval to metasediments of the Gimola group, but formed in different geological environments. Mafic rocks of the first group were regarded as relics of the upper oceanic crust, whereas metasediments were attributed to the active margin deposits of an ancient continent. In opinion of mentioned authors, juxtaposition of two rock groups is a result of later tectonic movements, when mafic volcanics were thrust over sedimentary rocks. This stratigraphic scheme is also shown in Fig. 2 (column III).

Data of this study allow us to consider the rock succession in the Kostomuksha belt as it is shown in column IV of Fig. 2. Differing from others, our scheme resembles best of all the scheme of Gor'kovets and Raevskaya. The investigation results substantiating our interpretation are presented below.

DATA ON ROCKS FROM THE KOSTOMUKSHA BELT AND THEIR SIGNIFICANCE FOR STRATIGRAPHIC INTERPRETATION

Kontokki Group. Basalts of this group show wide variations in the aluminum content and correspond to a series of the low- and high-Al tholeiites (TH1 after Condie, 1981). In the scheme of Gor'kovets *et al.* (1981), these rocks occupy two stratigraphic levels, and available geochemical characteristics (Matrenichev *et al.*, 1990) suggest their crystallization from parental magmas generated in the same magma source and subsequently fractionated under similar conditions. The analyzed Nd isotope composition in tholeiites of the lower Niemijarvi Formation (Table 1) revealed that the $\varepsilon_{Nd}(t)$

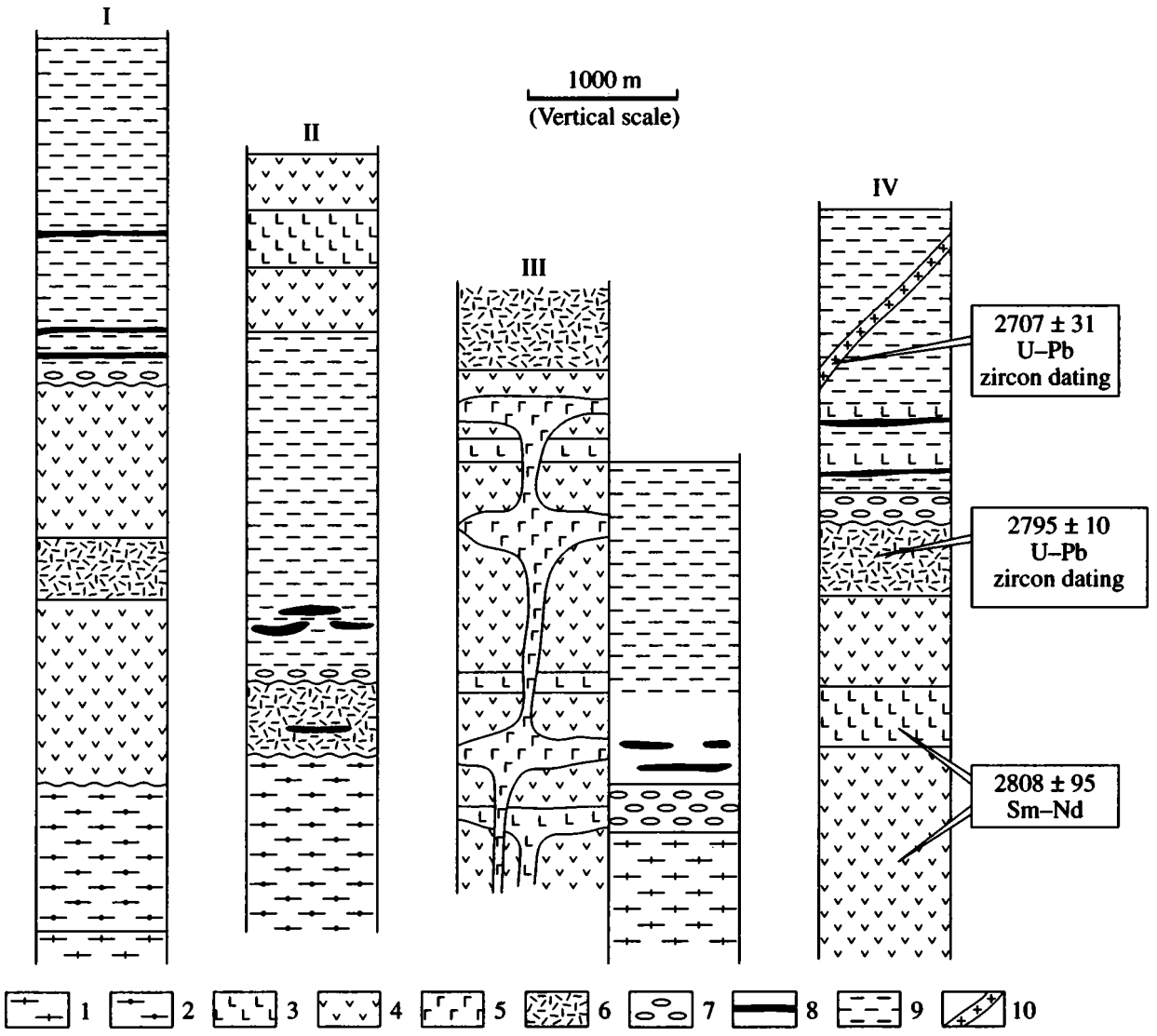


Fig. 2. Lithostratigraphy of the Kostomuksha greenstone belt: (1) plagiogranite and migmatite; (2) sillimanite-quartz schist; (3) komatiite; (4) basalt; (5) gabbroic sill; (6) acidic volcanics; (7) conglomerate; (8) ferruginous quartzite; (9) terrigenous metasediments; (10) granite porphyry. Columns: (I) after Gor'kovets *et al.* (1981); (II) after Kozhevnikov (1982); (III) after Puchtel *et al.* (1997); (IV) this work.

values in some of them are negative or close to zero, indicating an admixture of the ancient crustal material. This result is an important argument against the geodynamic model suggested by Puchtel *et al.* (1997). Using criteria of basic rocks contamination (Arestova, 1998), we selected five tholeiite samples without contamination signs. The Sm–Nd isochron for these samples and komatiites from the upper Ruvinvaara Formation (Fig. 3) corresponds in age to 2808 ± 95 Ma ($\varepsilon_{Nd}(t) = 2.9$; MSWD = 1.6). Within the limits of analytical errors, this date coincides with that obtained by Puchtel *et al.* (1997) for basalts and komatiites of the Ruvinvaara Formation, for which it is 2843 ± 39 Ma, $\varepsilon_{Nd}(t) = 2.8 \pm 0.2$, MSWD = 0.8. Both dates and geochemical criteria allow us to consider tholeiites and komatiites of the Niemijarvi and Ruvinvaara formations as coeval rocks.

The *acidic volcanics* of the Shurlovaara Formation (dacites and rhyodacites) are metamorphosed to the state of quartz–biotite–plagioclase gneisses. According to the bulk composition and distribution patterns of trace elements, they correspond to the group FII of acidic volcanics after Condie (1981). Preliminary data of U–Pb age determination in zircons (Sergeev *et al.*, 1990) showed that the rocks are 2801 ± 7 Ma old. Our result of age determination is shown in Fig. 4a plotted on the basis of data presented in Table 2 (rows 1–6). Small, light yellow and slightly hazy short-prismatic crystals of zircon from the rocks under consideration have distinctly corroded facets and represent one min-

Table 1. Sm–Nd geochemistry and isotopic parameters for basalts and komatiites from the Kostomuksha belt

Ordinal no.	Sample no.	Sm	Nd	Sm/Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(2.84)$
1	118 LJ-80	1.856	5.356	0.347	0.20897	0.513015 ± 11	2.95
2	14 Ar-85	1.633	4.689	0.3475	0.20999	0.513050 ± 15	3.26
3	23 Ar-85	1.853	5.281	0.3504	0.21166	0.513056 ± 11	2.77
4	25 Ar-85	2.126	6.161	0.3458	0.20812	0.512986 ± 12	2.69
5	44 Ar-85	1.956	5.9	0.3322	0.19999	0.512841 ± 25	2.81
6	20 Ar-85	2.175	6.207	0.351	0.21134	0.512948 ± 10	0.77
7	22 Ar 85	1.265	3.698	0.3432	0.20625	0.512895 ± 14	1.59
8	28. Ar-85	2.174	6.052	0.3587	0.21646	0.512829 ± 14	–3.44
9	36 Ar-85	1.304	3.863	0.3368	0.2035	0.512834 ± 14	1.39
10	43 Ar-85	2.657	7.204	0.3694	0.22241	0.512950 ± 12	–3.24
11	90 Ar-85	2.86	8.513	0.3361	0.20258	0.512828 ± 20	1.61
12	109 LJ-87	0.995	2.3	0.4348	0.26086	0.513990 ± 11	3.16
13	82 Ar-85	0.52	1.313	0.3939	0.23686	0.513490 ± 13	2.4

(1–11) Basalts of the Niemijarvi Formation, Kontokki Group; (12–13) komatiites of the Ruvinvaara Formation, Kontokki Group. The mixed HF and HNO_3 with the preliminarily added $^{146}Nd/^{149}Sm$ tracer were used to completely dissolve all samples at the temperature of 1000°C. Conventional two-step ion exchange technique was used to extract REE and to separate Sm and Nd. Isotopic analysis was carried out using the multicollector mass spectrometer Finigan MAT-261 in the two-tape regime.

eral generation. Their inner structure is homogeneous, with occasional and thin growth zones. The identical morphological features are established for zircons from all three metadacite samples of variable, medium- to fine-grained texture. As one can see from analytical data (Table 2, Fig. 4a), the U–Pb isotopic system is preserved best of all in the largest zircon crystals. According to the upper intersection with concordia, the crystallization time of zircons in metadacites is 2795 ± 10 Ma, MSWD = 2. This date is almost identical to two dating results obtained earlier and equal to 2801 ± 7 Ma (Sergeev *et al.*, 1990) and 2795 ± 29 Ma (Samsonov *et al.*, 1995).

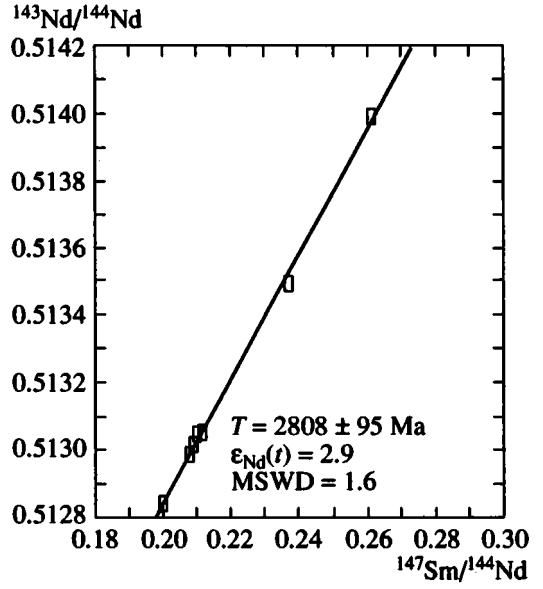


Fig. 3. Sm–Nd isochron age of basalt and komatiites from the Kostomuksha belt (T = 2808 ± 95 Ma; $\varepsilon_{Nd}(t)$ = 2.9; MSWD = 1.6).

Gimola Group. *Conglomerates.* The intraformational conglomerates at the base of the Gimola Group (Raevskaya *et al.*, 1992) include pebbles of metarhyodacites (60%), and also of amphibole schists and amphibolites (30–40 %). As one can see in Fig. 5, metarhyodacite pebbles and volcanics of the Shurlovaara Formation are identical in composition. This supports the idea of Gor'kovets *et al.* (1981) that conglomerate beds overlie acidic volcanics.

Terrigenous metasediments of the Gimola Group are poorly differentiated, immature, and similar to graywackes known in many greenstone belts of the Late Archean. The model provenance of the rocks presumably was composed of basic and acidic volcanic rocks that occurred in approximately equal proportions like their pebbles in conglomerates (Mil'kevich and Myskova, 1998). Volcanics of the Kontokki Group can be regarded as the local source of the terrigenous mate-

Table 2. U–Pb isotopic parameters for zircons separated from rocks of the Kostomuksha belt

Ordinal no.	Sample no. and fraction characteristics	Sample weight	Concentration, ppm		Measured isotopic ratios			Atomic ratios		$^{207}Pb/^{206}Pb$ age, Ma
			U	Pb	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	
	Metadacite									
1	4, +80	2.70	129	73.0	11080	0.19798	0.10138	0.50633	13.761	2802
2	4, 60–80	3.81	145	72.2	7380	0.19903	0.11165	0.44144	12.029	2807
3	4, 60–80, raa 25	1.56	201	118	3017	0.19981	0.11714	0.51812	14.009	2794
4	4b, 50–80	3.53	153	85.3	3250	0.19881	0.11482	0.49266	13.269	2788
5	4b, –50	5.07	179	98.3	6727	0.19881	0.12509	0.48233	13.117	2804
6	4c, –50	0.91	193	104	3672	0.20001	0.13189	0.47409	12.876	2801
	Plagioporphyry									
7	9a, hazy, +45	0.60	1115	599	4400	0.18760	0.15600	0.46511	11.868	2699
8	9a, +45; raa 60	9.00	863	490	11150	0.18664	0.15801	0.48974	12.542	2705
9	9a, raa 20	3.99	864	512	7140	0.18639	0.19276	0.49781	12.69	2697
10	9a, translucent, +45	1.13	767	427	2110	0.19085	0.15630	0.47895	12.238	2701
11	9a, translucent, raa 40	5.35	769	443	3870	0.18939	0.16491	0.49228	12.656	2711
	Microcline granite									
12	79/4, 60–80, long-prismatic D = 4.2	1.54	515	278	1569	0.19007	0.14204	0.4669	11.75	2676
13	79/4, 60–80, short-prismatic D = 4.2	0.75	461	254	2610	0.18681	0.11750	0.4952	12.45	2675
14	79/4, bulk fraction, raa 64	4.37	504	228	1430	0.19007	0.14138	0.3917	9.817	2667
15	79/4, 60–80, prismatic D = 4.4	1.05	629	345	1995	0.18800	0.11771	0.4855	12.19	2672

Fraction size in μm; (raa) residue after abrasion and its percentage; (D) zircon density, g/cm^3. Zircon decomposition and extraction of U and Pb were carried out in accordance with procedure described by Krogh (1973). Laboratory contamination is below 0.5 mg for Pb and below 0.1 mg for U. The U and Pb isotope ratios are measured using mass spectrometer MI-1320; measurement errors are less than 65%, and their correlation coefficient is 0.98. All calculations are performed using the ISOPLOT program of Ludwig (1991).

rial composing the metasediments. This inference finds a support in the Nd isotope composition measured in two samples of metamorphosed silty pelites, for which the initial ε_{Nd} values are found to be positive (+2.2 and +4.1).

Talc–chlorite schists. Ultramafic schists of the talc–chlorite and chlorite–actinolite composition are intercalated in the lower part of the Gimola Group (Kostomuksha Formation) with ferruginous quartzites, carbonaceous schists, and metagraywackes. Chernov (1964) considered these rocks as metavolcanics. Afterward, they were attributed to intrusive rocks and excluded from the succession (Gor'kovets *et al.*, 1981, Gor'kovets and Raevskaya, 1988). On the basis of lithological and geochemical data, we arrived at the conclusion that at least a part of the formation consists of metavolcanics corresponding in composition to peridotitic komatiites. These ultramafic rocks are now transformed into talc–chlorite, tremolite–chlorite, and chlorite–actinolite schists devoid of primary structural patterns and containing dolomite and Mg-biotite in a variable proportion. Upper intervals (1–3 m thick) of ultramafic beds are essentially dolomitic in composition and show porphyroblasts and lentils of Mg-biotite. This structure of the beds likely indicates that we deal with thin komatiite interlayers affected by intense diagenesis. According to the bulk composition and distribution patterns of trace elements, the least altered rock varieties are similar to komatiites of the Ruvinvaara Formation of the Kontokki Group (Mil'kevich and Arestova, 1998). Consequently, the ultrabasic magmatism typical of the latter was episodically active as well during the accumulation of ferruginous silica-rich terrigenous sediments of the Gimola Group that appears to be continuing the succession and does not represent, together with granitoids of the basement, an independent terrane of an active continental margin, as

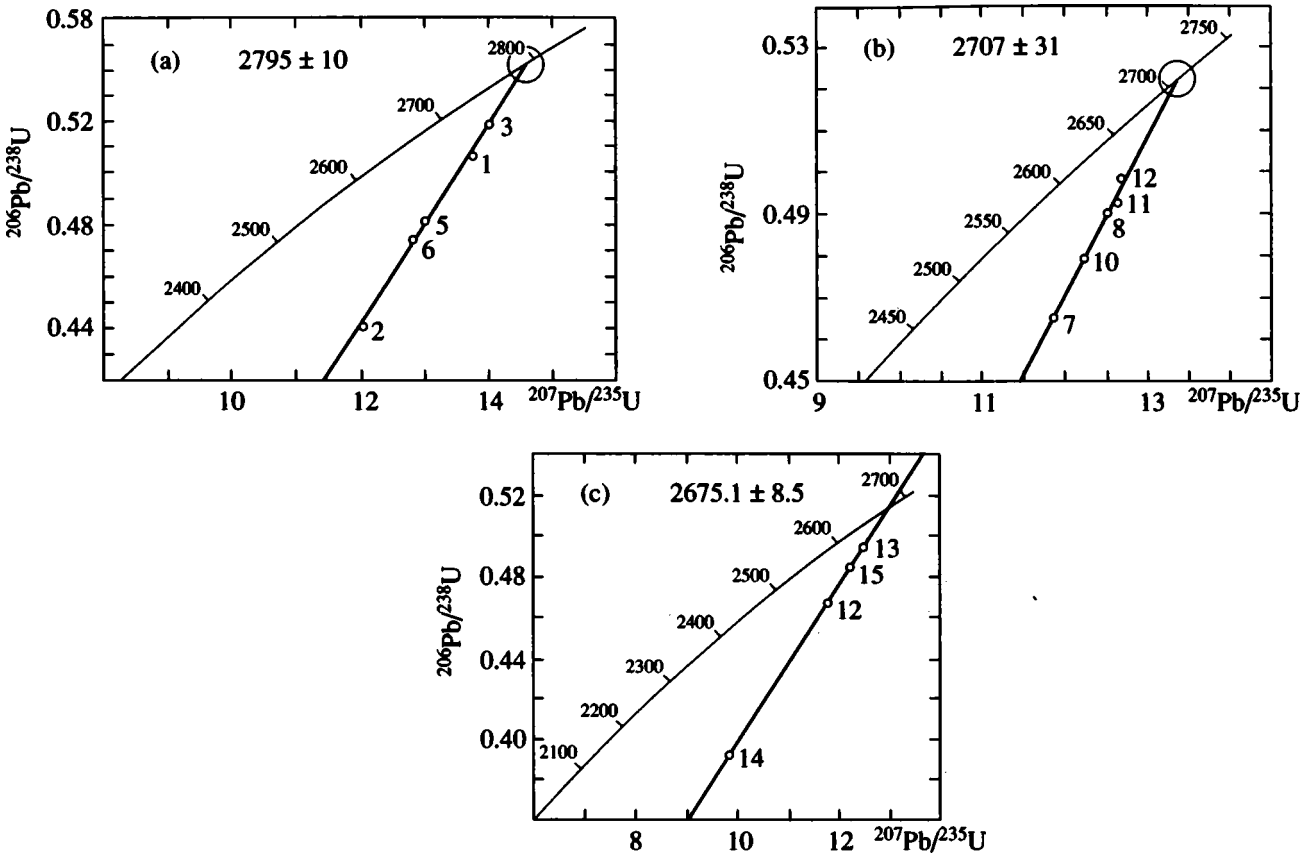


Fig. 4. Concordia diagrams for: (a) zircons from metadacites of the Shurlovaara Formation, Kontokki Group, (b) plagioclase porphyry intruding rocks of the Gimola Group, and (c) microcline granites. Data point numbers correspond to ordinal numbers in Table 2.

it was suggested by Puchtel *et al.* (1997) (see column III in Fig. 2).

AGE OF INTRUSIVE BODIES CUTTING DEPOSITS IN THE KOSTOMUKSHA BELT

Deposits of the Kontokki and Gimola groups are cut by intrusive bodied different in composition.

Diorite-plagiogranites of the Central stock intruding metabasalts of the Kontokki Group are found to be 2720 ± 15 Ma old according to results of U–Pb zircon dating (Samsonov *et al.*, 1995).

Metamorphic and folding events separate dikes and intrusions of plagioporphyry from the formation periods of the Kontokki and Gimola groups. The U–Pb zircon dating was also used to define age of the plagioporphyry dike cutting schists of the Gimola Group. The dike was sampled near the southern contact of the Shurlovaara granite massif (Fig. 1). Zircons from the sample are represented by rounded subhedral grains light brown in color and having the elongation coefficient less than 2 (Sample 9a in Table 2, rows 7–11). In general, the grains are turbid, weakly translucent, and devoid of clear crystallographic shape. Translucent and semitranslucent grains with a reduced prismatic habit represent about 20% of the zircon fraction. We analyzed both grain varieties subjecting them to abrasion of variable intensity, but failed, however, to remove all products of recrystallization and to extract the original homogeneous zircons. The noticeable dispersion of data points in Fig. 4b is responsible for the high uncertainty of the age determination equal to 2707 ± 31 Ma and the obtained value of MSWD = 3. Obtained age value can be considered only as the minimum date for the plagioporphyry from the Kostomuksha belt.

The youngest intrusions in the belt are those of microcline granite. We determined age of these intrusions using the Shurlovaara massif as an example (Fig. 1). Zircon crystals from the massif (Table 2, rows 12 and 13) are translucent, yellow-orange in color, having the jacinth habit and clear lustrous facets. Abundant amphibole intergrowth and chaotically dispersed gas inclusions are characteristic of zircon crystals. The material was powdered and divided in the Clerici solution to extract the heavy fraction. Further, we analyzed this fraction and crystal cores obtained after abrasion procedure. The isochron plotted on the basis of four data points defines the crystallization time of microcline granites as equal to 2679 ± 8 Ma (Fig. 4c).

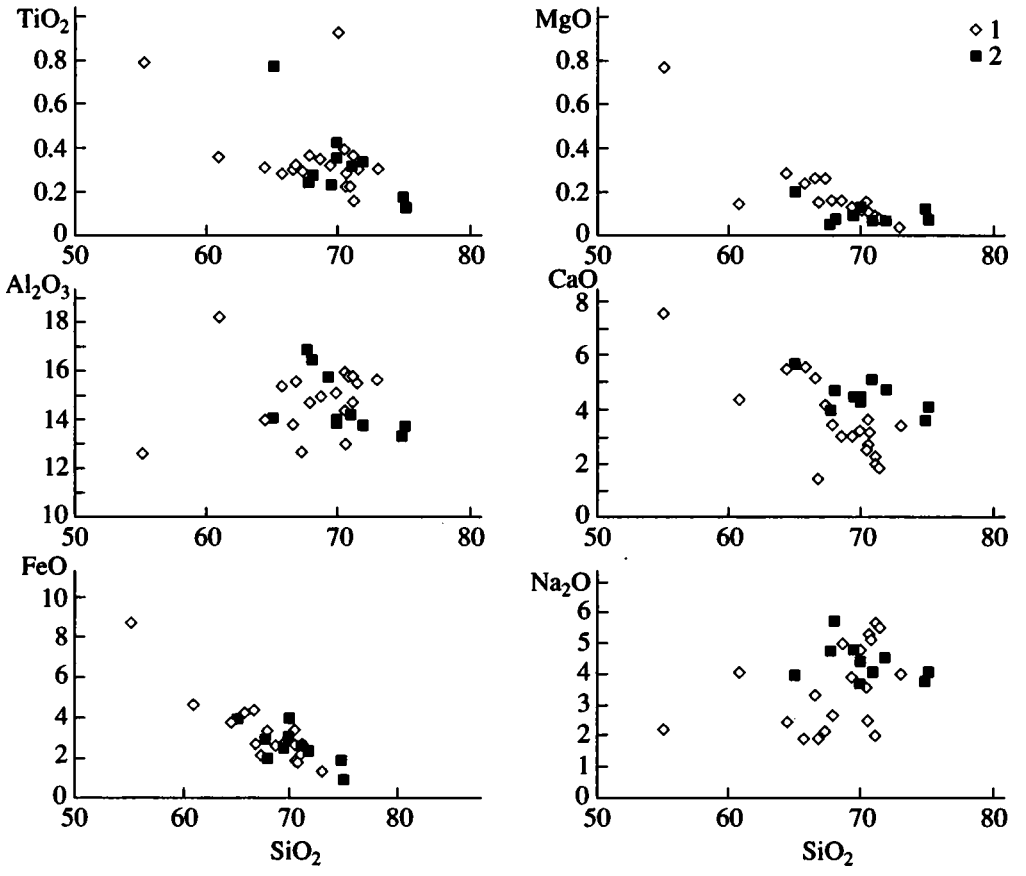


Fig. 5. Diagrams illustrating compositions of acidic volcanics from the Kontokki Group (1) and pebbles from basal conglomerates of the Gimola Group (2).

CONCLUSION

Geochemical, isotopic, and geochronological data allow us to suggest the new stratigraphic scheme for Lopian deposits in the Kostomuksha greenstone belt (Fig. 2, column IV). Basal in the succession are metabasalts and metakomatiites (Niemijarvi and Ruvinvaara formations of the Kontokki Group) that underlie metadacites, metarhyodacites, and their tuffs (Shurlovaara Formation of the Kontokki Group). Metasediments of the Gimola Group rest on basal conglomerate beds overlying these rocks.

The supracrustal rocks were deposited at the time of continental rifting, as it was suggested earlier (*Zelenokamennye poyasa..*, 1988).

The estimated formation time of the lower mafic part of the rock succession is 2808 ± 95 Ma (this work) or 2843 ± 39 Ma (Puchtel *et al.*, 1997). The obtained date of 2795 ± 10 Ma characterizes age of acidic volcanics.

The time range of metasediments in the Gimola Group is limited by the date of 2795 ± 10 Ma characterizing the underlying acidic volcanics, which presumably constituted a part of provenance for terrigenous metasediments. The minimum age limit of the group is defined by the date of 2707 ± 31 Ma obtained for the plagoigranite porphyry body intruding the schists.

The difference between available interpretations of the rock succession in the Kostomuksha belt is a consequence of complex tectonic history of the belt that resulted in emergence of gently dipping and oblique shear zones. The origin time of the latter is close to the age of the Shurlovaara granite massif (2679 ± 8 Ma).

ACKNOWLEDGMENTS

We are grateful to C.Z. Yakovleva, E.S. Bogomolov, and A.V. Kovalenko for their assistance in the study. The work was supported by the Russian Foundation for Basic Research, project no. 96-05-64657.

Reviewers M.A. Semikhatov and K.I. Heiskanen

REFERENCES

Arestova, N.A., Contamination of Basic Melts and Related Constraints for Geodynamic Reconstructions, in *Problemy genezisa magmaticheskikh i metamorficheskikh porod* (Problems of Genesis of Magmatic and Metamorphic Rocks), St. Petersburg: St. Petersburg Gos. Univ., 1998, pp. 64–65.

Chernov, V.M., Formation Environments of the Kostomuksha Iron Ore Field, *Izv. Karel. Kol. Fil. Akad. Nauk SSSR*, 1959, no. 3, pp. 17–27.

Chernov, V.M., *Stratigrafiya i usloviya osadkonakopleniya vulkanogennykh (leptitovykh) zhelezisto-kremnistykh formatsii Karelii* [Stratigraphy and Sedimentation Environment of Volcanogenic (Leptite) Ferruginous–Siliceous Formations of Karelia], Moscow: Nauka, 1964.

Condie, K.C., *Archean Greenstone Belts*, ESPC, 1981.

Gor'kovets, V.Ya. and Raevskaya, M.B., The Kostomuksha Structure, in *Vulkanizm arkheiskikh zelenokamennykh poyasov* (Volcanism of the Archean Greenstone Belts), Leningrad: Nauka, 1981, pp. 69–72.

Gor'kovets, V.Ya. and Raevskaya, M.B., The Gimola–Kostomuksha Greenstone Belt, in *Komatiity i vysokomagnezial'nye vulkanity rannego dokembriya Baltiiskogo shchita* (Early Precambrian Komatiites and High-Manganese Volcanics of the Baltic Shield), Leningrad: Nauka, 1988, pp. 136–148.

Gor'kovets, V.Ya., Raevskaya, M.B., Belousov, E.F., and Inina, K.A., *Geologiya i metallogeniya raiona Kostomukshskogo zhelezorudnogo mestorozhdeniya* (Geology and Metallogeny of the Kostomuksha Iron Ore Field), Petrozavodsk: Kareliya, 1981.

Kozhevnikov, V.N., *Usloviya formirovaniya strukturno-metamorficheskikh parageneziov v dokembriiskikh kompleksakh* (Formation Conditions of Structural–Metamorphic Parageneses in Precambrian Complexes), Leningrad: Nauka, 1982.

Krogh, T.E., A Low-Contamination Method for Hydrothermal Decomposition of Zircon and Extraction of U and Pb for Isotopic Age Determination, *Geochim. Cosmochim. Acta*, 1973, vol. 37, no. 3, pp. 485–494.

Lazarev, Yu.I. and Kozhevnikov, V.I., *Strukturno-petrologicheskoe izuchenie granitizatsii* (Structural–Petrological Study of Granitization), Leningrad: Nauka, 1973.

Ludwig, K.R., ISOPLOT Program USA, *Open-File Rep. Geol. Surv.*, 1991.

Matrenichev, V.A., Lobach-Zhuchenko, S.B., Arestova, N.A., *et al.*, Petrology of Karelian Archean Volcanics (the Problem of Geodynamics of Greenstone Belts), in *Geologiya i geokhronologiya dokembriya Vostochno-Evropeiskoi platformy* (Precambrian Geology and Geochronology of the East European Platform), Leningrad: Nauka, 1990, pp. 187–198.

Mil'kevich, R.I. and Arestova, N.A., Diagenetic Changes in Metakomatiites of the Gimola Group and Their Significance for Geodynamics of the Kostomuksha Greenstone Belt, in *Osadochnye formatsii dokembriya i ikh rudonosnost* (Precambrian Sedimentary Formations and Ore Deposits), St. Petersburg: Inst. Geol. Geochronol. Dokembr. Ross. Akad. Nauk, 1998, pp. 43–44.

Mil'kevich, R.I. and Myskova, T.A., Late Archean Terrigenous Metasediments of West Karelia (Lithology, Geochemistry, and Model Provenance), *Litol. Polezn. Iskop.*, 1998, no. 2, pp. 177–194.

Puchtel, I.S., Hofmann, A.W., Jochum, K.P., Mezger, K., Shchipansky, A.A., and Samsonov, A.V., The Kostomuksha Greenstone Belt, NW Baltic Shield: Remnant of a Late Archaean Oceanic Plateau?, *Terra Nova*, 1997, no. 9, pp. 87–90.

Raevskaya, M.B., Gor'kovets, V.Ya., Svetova, A.I., and Volodichev, O.A., *Stratigrafiya dokembriya Karelii: Opornye razrezy verkhnearkheiskikh otlozhenii* (The Precambrian Stratigraphy of Karelia: Upper Archean Reference Sections), Petrozavodsk: Karel. Nauchn. Tsentr Ross. Akad. Nauk, 1992.

Samsonov, A.V., Puchtel, I.S., Bibikova, E.V., and Zhuravlev, D.Z., Petrology and Geochronology of Felsic Volcanic and Plutonic Rocks of the Kostomuksha Greenstone Belt, W Karelia, in *Precambrian of Europe*, St. Petersburg: Inst. Precambrian Geol. Geochronol. Russ. Acad. Sci., 1995, p. 95.

Semikhatov, M.A., Shurkin, K.A., Aksenov, E.M., *et al.*, New Stratigraphic Scheme for the Precambrian of the USSR, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1991, no. 4, pp. 3–13.

Sergeev, S.A., Levchenkov, O.A., Arestova, N.A., *et al.*, Age Limits of Iron-Bearing Deposits in the Kostomuksha Structure, Karelia, in *Izotopnoe datirovanie endogennykh rudnykh protsessov* (Isotope Dating of Endogenic Ore Processes), Kiev: Inst. Geol. Fiz. Mineral., 1990, pp. 72–73.

Zelenokamennye poyasa fundamenta Vostochno-Evropeiskoi platformy (The Greenstone Belts of the East European Platform Basement), Leningrad: Nauka, 1988.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 327–352. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 11–39.
Original Russian Text Copyright © 2000 by Gnilovskaya, Veis, Bekker, Olovyanishnikov, Raaben.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Pre-Ediacarian Fauna from Timan (Annelidomorphs of the Late Riphean)

M. B. Gnilovskaya*, A. F. Veis, Yu. R. Bekker***, V. G. Olovyanishnikov****, and M. E. Raaben****

** Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, nab. Makarova 2, St. Petersburg, 197034 Russia*

*** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*

**** All-Russia Karpinskii Research Institute of Geology, Srednyi pr. 74, St. Petersburg, 199026 Russia*

***** Institute of Geology, Komi Research Center, Ural Division, Russian Academy of Sciences, Pervomaiskaya ul. 54, Syktyvkar, 167000 Russia*

Received November 12, 1998

Abstract—The Timan biota from Russia and Huainan biota from China proved the pre-Ediacarian Metazoa did exist in the past. In Russia, the genus *Parmia* Gnilovskaya of the pre-Ediacarian annelidomorphs, whose construction has distinct homonomous metamerization of their bodies, is established for the first time in the Upper Riphean deposits of the Dzhezhim Parma borehole section (southern Timan). Diverse assemblage of organic-walled microfossils also known from the Upper Riphean in Siberia, southern Urals, and China is recovered from the *Parmia*-bearing beds. The distinguished, most ancient Metazoa and coexisting microfossils are described, and annelidomorphs of Timan are compared with their counterparts from the Late Riphean Huainan biota of eastern China. The comparative morphological analysis of annelidomorphs from both macrobiotas is also presented.

Key words: *Upper Riphean; macro- and microfossils; taxons Parmia, Pararenicola, and Protoarenicola; pre-Ediacarian Metazoa; Huainan (China); Timan (Russia).*

M. Glaessner, who was first to describe the Ediacarian fauna, suggested once and again that there should be the pre-Ediacarian history of the fauna. The Huainan biota that was discovered in the North Chinese platform at the beginning of the 1960s was the first evidence in favor of his assumption. This biota from the Jiuliqiao Formation of the lowermost Sinian, an analogue of the upper Upper Riphean (Wang, 1982), included the worm-like organisms attributed to genera *Pararenicola* Wang and *Protoarenicola* Wang. The very first publication in English (Sun *et al.*, 1986) attracted interest and triggered a vivid discussion among experts not excepting Glaessner (1987) and Cloud(1986). After the natural stage of skeptical consideration and authentication, the aforementioned fossils from the Huainan biota of China were dated back to the Late Riphean and confidently classed with the pre-Ediacarian Metazoa as having the distinct body metamerization (Chen, 1988).

In Russia, Tereshko and Kirillin (1990), who studied cores from the Borehole 80 drilled by the Vychegda Prospecting Expedition in the Dzhezhim Parma structure (southern Timan), discovered ancient macrofossils in the borehole interval initially attributed to the Vendian. Soon afterward, Gnilovskaya investigated in detail their collection of 83 paleontological samples taking into consideration the peculiar character of macrofossils and very ancient level of their occurrence. After comparison with the Huainan biota of China, the materials turned out to be very informative.

The study enabled recognition of the new genus *Parmia* Gnilovskaya. Preliminary results were reported at the Third International Symposium on the Cambrian System (Novosibirsk, 1990), where Prof. S. Conway-Morris, an expert in soft-body fossils from the Cambridge University, participated in discussion, and also at the International Symposium "Evolution of Ecosystems" (Moscow, 1995). We consider our consultations with G.N. Buzhinskaya, an expert in annelids from the Institute of Zoology, Russian Academy of Sciences, as very valuable for understanding the nature of *Parmia*. To enhance the first description of *Parmia* (Gnilovskaya, 1998), we present here the complete diagnosis of the genus characterizing, according to Gnilovskaya, the worm-like organism, whose both endings are preserved and show the distinct homonomous metamerization of the body. Most likely, the organisms exemplify ancient ancestors of annelids. One section of the paper is specially devoted to the history of discovery and investigation of the Huainan biota consisting of unique Late Riphean fossils from the North Chinese platform, some of which resemble *Parmia* from Timan in the taxonomic position and geological age. In order

to correctly date the *Parmia*-bearing deposits in Timan, we considered in detail the coexisting assemblage of representative organic-walled microfossils. Analogues of the latter are known in the Late Riphean biotas from the southern Urals and Siberia, and, in opinion of A.F. Veis, this situation is favorable for elucidating the stratigraphic level of microbiota in the general succession of the Riphean and Vendian deposits in Russia and China.

The analysis of microbiota is important as well from the standpoint of general geological situation in the Dzhezhim Parma area, as there is a room for alternative speculations concerning stratigraphic and structural relations between the Upper Precambrian strata exposed here. Being out of accord in some issues, we all share the viewpoint that the beds with annelidomorphs belong to the Upper Riphean (pre-Vendian or pre-Ediacarian) level. This is clearly evident from the character of coexisting microbiota and from similarity between *Parmia* and Chinese genera *Protoarenicola* Wang and *Pararenicola* Wang.

Describing deposits that yield *Parmia*, we feel it impossible to use the term Vychegda Formation accepted by local geologists, because the synonymous name was already given to the middle subformation of the Vendian Ust-Pinega Formation in 1971 by L.F. Solontsev and E.M. Aksenov, who distinguished the stratotype of the unit in the Kotlas Borehole (see in *Stratigraficheskii slovar'*..., 1994). Nevertheless, it has been and is rightful now to consider the *Parmia*-bearing glauconite siltstones as an independent lithostratigraphic unit having no analogues among the Upper Precambrian succession exposed in the Dzhezhim Parma and other areas of Timan. The unit's rank is unclear, because uninterrupted rock successions are missing from the study region, and we term it below in the open nomenclature as the *Parmia*-bearing unit.

GEOGRAPHIC AND STRATIGRAPHIC POSITION OF THE STUDIED FOSSILS

The Dzhezhim Parma Height is located within the upper Ust-Nema Loop of the Vychegda River and represents the southeastern terminus of the Timan Ridge; the ridge extends from here northwestward to the Chesha Bay of the Barents Sea along the distance of 750 km (Fig. 1). The Timan Ridge consists of a series of heights ranging in altitude from 300 to 450–460 m; local names for most prominent elevations are either "parmas" in the south of the ridge, or "kamni" in the north. The elevations correspond to discrete antiforms in the Timan Ridge structure, and the Upper Precambrian rocks constituting the antiform cores are concealed under Paleozoic deposits in other areas of the ridge. Most remarkable elevations are the Chetlasskii and Tsil'menskii "kamni" in the central part of the Timan Ridge (Fig. 1).

The listed areas are the sites of reference sections in the main western zone of Upper Precambrian deposits in Timan. The unified stratigraphic scheme accepted in 1983 (*Rifei i vend*..., 1987) delineates the Middle and Upper Riphean deposits in the Chetlas–Tsil'ma zone of the Timan, where the Dzhezhim Parma is situated. The Middle Riphean spans the Chetlas Group divided from the base upward into the Svetlyi, Bobrovaya, and Vizinga formations. The Upper Riphean Bystrukha Group includes the An'yuga (= Dzhezhim), Vorykva (or its facies analogue the Rochuga Formation), Pav'yuga, and Pauna formations. The Middle Riphean age of the Chetlas Group appears to be doubtful, as is shown below. In the Dzhezhim Parma, the section is incomplete and includes the Vizinga, An'yuga (Dzhezhim), and Pav'yuga formations only.

The Upper Precambrian rocks of the Dzhezhim Parma either have a discordant contact with overlying Devonian deposits, or are thrust over the latter in the southwest; they are exposed within a band of thick forest vegetation. The band is up to 8 km wide and about 35 km long; it extends from the east-southeast to the west-northwest. From the viewpoint of tectonics, the Timan Ridge is divided into two structural stages (Olovyanishnikov, 1998). Like in other areas of the ridge, Precambrian rocks of the Dzhezhim Parma are constituents of the lower stage. Within the area, they dip almost everywhere toward the northeast. The structure of the area was interpreted in a very different manner. For instance, Zhuravlev and Osadchuk (1963) considered it as an asymmetric faulted anticline. Raznitsyn (1961), whose map of the area turned out to be almost unchangeable with respect to position of geological boundaries, believed that the Precambrian rocks form here a syncline that has a gentle, locally folded southwestern limb and is replaced in the northeast by the steeply dipping recumbent anticline. In opinion of Olovyanishnikov, however, the area is of an imbricated structure consisting of three tectonic sheets successively thrust from the northeast toward the southwest. The difference between interpretations is a result of poorly understood succession of lithostratigraphic units distinguished by B.V. Miloradovich in the 1930s, when he defined them as the Lower Devonian shale sequence and the Dzhezhim Member of Middle Devonian sandstones and conchoidal dolomites. In the 1950s, the rocks were attributed to the Proterozoic (Chochiya, 1955), and later on, to the Riphean (Raznitsyn, 1961; Zhuravlev and Osadchuk, 1963). As mentioned above, the deposits under consideration correspond to the Vizinga, Dzhezhim (An'yuga), and Pav'yuga formations of the Unified Stratigraphic Scheme of the Riphean and Vendian in the North European part of Russia (*Rifei i vend*..., 1987). Their correlation with deposits in other areas of Timan and in the western slope of the Urals is of prime significance for regional stratigraphy. It is a difficult problem, however, because paleontological data from the Dzhezhim Parma area are known for the Pav'yuga Formation only.

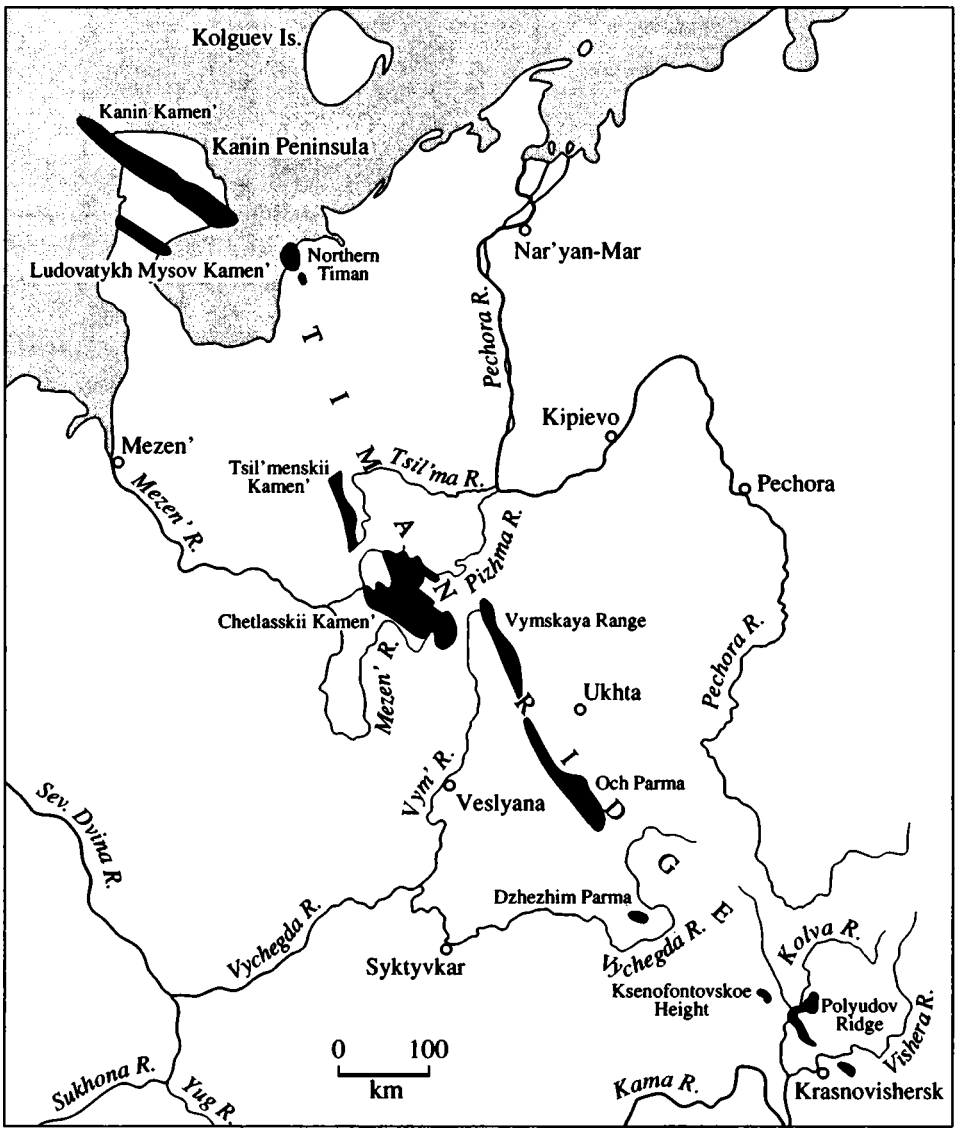


Fig. 1. Scheme of distribution of Upper Precambrian rocks (black) in the Timan Ridge, Kanin Peninsula, and Polyudov Ridge.

In addition, tectonic boundaries widespread in the area (Fig. 3) make the stratigraphic succession indistinct.

The *Parmia*-bearing unit appears to be in tectonic contact with other exposed Precambrian formations (Tereshko and Kirillin, 1990). Rocks of the unit have never been found exposed at the surface. Several boreholes penetrated them within the 700-m-wide zone of a limited extension that is adjacent to outcrops of the Pav'yuga (Vapol in other nomenclature) Formation, whose beds steeply dip northeastward. Beds of the *Parmia*-bearing unit dip more gently in the same direction. The base of the unit has not been detected; above the upper erosion surface, the unit is discordantly overlain either by Devonian (Frasnian) sediments, or by Quaternary morainal deposits. The unit mostly consists of gray colored rocks: siltstones, silty shales, and shales, all intercalated with rare interlayers and lentils of sandstones and carbonates. *Parmia* remains are confined to siltstone and fine-grained sandstone beds recovered by Borehole 80. The borehole section divisible into three principal members (Fig. 4) was described in detail by Tereshko and Kirillin.

The lower red member is distinguished within the depth interval (d.i.) of 98.0–71.4 m and includes the following beds (from the base upward):

(1) brick-red clayey siltstone with basal dolomite matrix (d.i. 98.0–90.5 m);

(2) brick-red finely laminated siltstone with separate interlayers up to 10 cm thick, where basal matrix is composed of dolomite (d.i. 90.5–81.5 m);

(3) alternating brick-red silty dolomite and brown siltstone (d.i. 81.5–79.3 m);

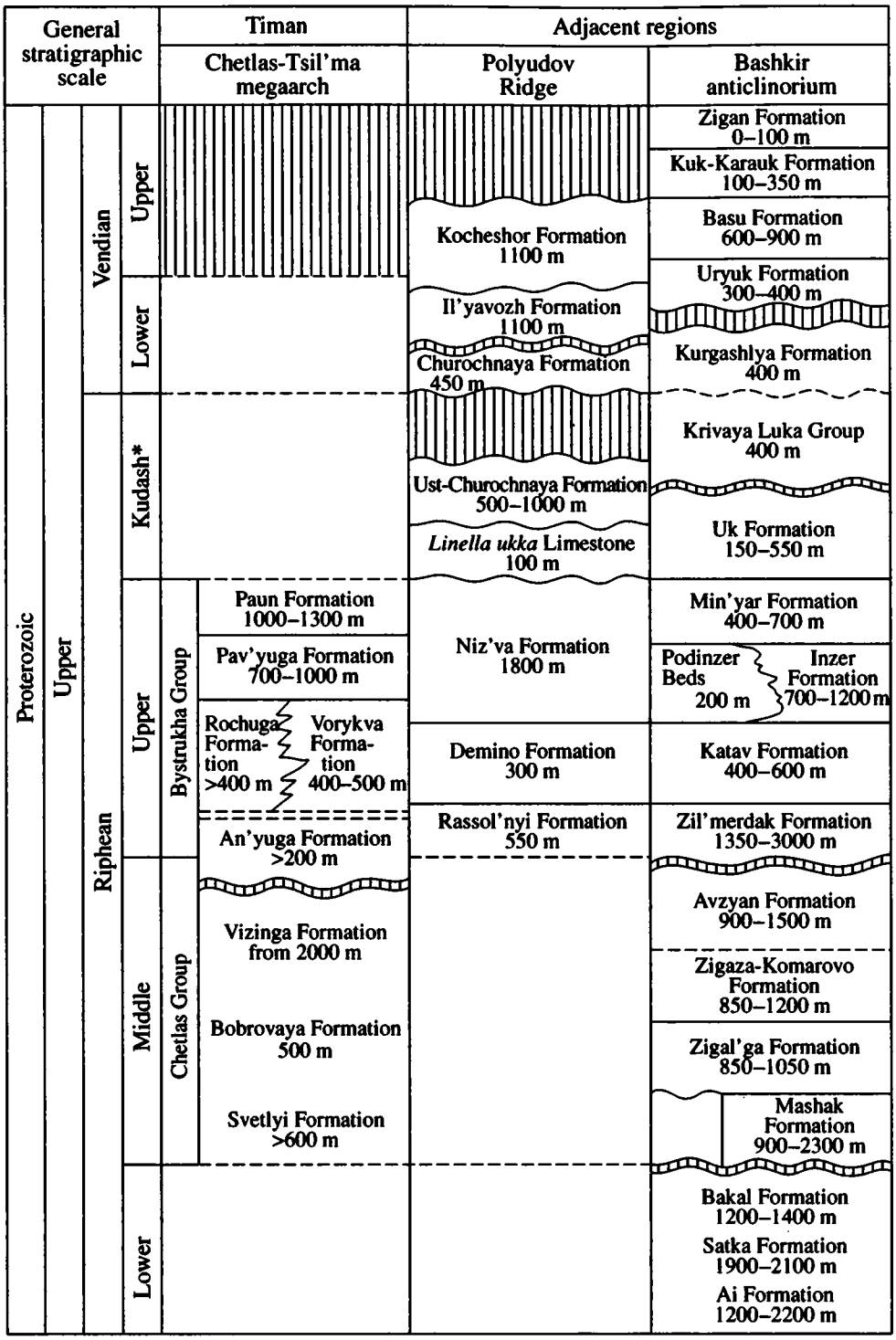


Fig. 2. Correlated Upper Precambrian subdivisions of the Chetlas–Tsil'ma (western) zone of Timan and adjacent regions (after *Rifei i vend...*, 1987).

(4) brick-red flaggy and finely laminated siltstones (d.i. 79.3–76.6 m);

(5) brick-red siltstone with fine horizontal lamination; in the upper portion, the rock is less bright, with color changing to dark violet-gray (d.i. 76.6–73.2 m);

(6) fine alternation of violet-gray and greenish gray siltstones (d.i. 73.2–71.4 m).

The middle member of Parmia-bearing siltstones is penetrated within the depth interval of 71.4–41.0 m. The main rock types here are greenish to dark gray

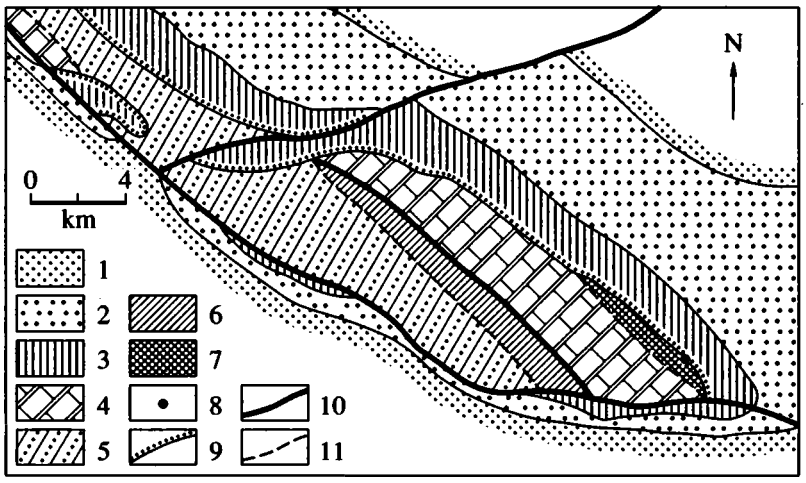


Fig. 3. Geological scheme of the Dzhezhim Parma area. (1–3) Paleozoic deposits: Permian (1), Carboniferous (2), and Devonian (3). (4–6) Upper Precambrian formations: Pav'yuga (4), Dzhezhim (5), and Vizinga (6). Other symbols: (7) *Parmia*-bearing unit; (8) site of Borehole 80; (9) base of Paleozoic deposits; tectonic boundaries observed (10) and inferable (11).

flaggy siltstones intercalated with rare interlayers of light gray sandstones. Annelidomorph remains and associated microfossils are abundant at seven levels of the member.

The upper gray member consists of flaggy siltstones enclosing interlayers of sandstones and silty pelites. It spans the depth interval of 41.0–18.7 m, being overlain by the Quaternary loam.

Siltstones and silty pelites of two upper members are greenish to dark gray and black in color and show the fine lamination of horizontal and lenticular-wavy types. They enclose interlayers (to 10 cm thick) and lentils of light to greenish gray compact sandstones.

In the section of Borehole 80, the gently dipping beds of the *Parmia*-bearing unit are less that 80 m thick. In other drilling sites, these rocks are thinner. For instance, Borehole 10 recovered the alternating sedimentary microrhythms composed of glauconite-bearing oligomictic sandstone and slates within the depth interval of 163.8–153.2 m. In the section of Borehole 19, the depth interval of 158.0–140.2 m is characterized in the basal part by a fine intercalation of clayey siltstones and silty shales also bearing glauconite and impregnated by pyrite veinlets; the overlying beds of gray to cherry-gray feldspar–quartz siltstones experienced limonitization in the weathering-crust zone.

Siltstones of the *Parmia*-bearing unit are of the feldspar–quartz, quartz–feldspar, and polymictic types. Their clastic fraction consists of quartz, plagioclase, K-feldspar, biotite, muscovite, and rock fragments (clay, slate, and rare acidic to basic volcanic rocks). The poorly rounded clastic material is cemented by the carbonate–chlorite–hydromica matrix. Siltstones and medium- to fine-grained sandstones always contain glauconite, whose grains are larger than the neighboring quartz grains. Accessory minerals of the rocks are zircon, sphene, tourmaline, leucoxene, barite, sphalerite, and galena. In general, the rocks are rich in potassium (K_2O content in clayey siltstones is up to 3–4.5%), and P_2O_5 concentration in sandstones can be as high as 1.12%.

Tereshko and Kirillin (1990) suggested that the *Parmia*-bearing unit could be as thick as 1000 m. This is obviously an exaggeration, because the distribution zone of rock, where they gently dip northeastward, is only 700 m wide. Anyway, the respective rocks penetrated by boreholes are les than 100 m thick, and Olovyanishnikov suggested that their complete thickness is not greater than 200–300 m.

Rocks of the unit are insignificantly altered and always bear glauconite thus being distinct from other Riphean formations of Timan, in particular, from the Upper Precambrian rock complex exposed in the Dzhezhim Parma.

The mentioned complex is 2–2.5 km thick in total. Presenting below brief characteristics of its constituent formations, we should emphasize first that the Unified Stratigraphic Scheme is incompatible with the alternative suggested by Olovyanishnikov. The difference is essential and concerns the stratigraphic relationship between the siliciclastic and carbonate (dolomite) parts of the complex. According to the unified scheme that accepted widely, siliciclastic deposits underlie the upper carbonate part of the section. This concept well agrees with the early inferences by Miloradovich (1938) and Rostovtsev (1948), and has been supported soon afterward in the course of correlation with the sections studied in the western slope of southern Urals, for instance, in the Polyudov Ridge located not far away (Chochiya, 1955; Vladimirskaya, 1955) and also in the

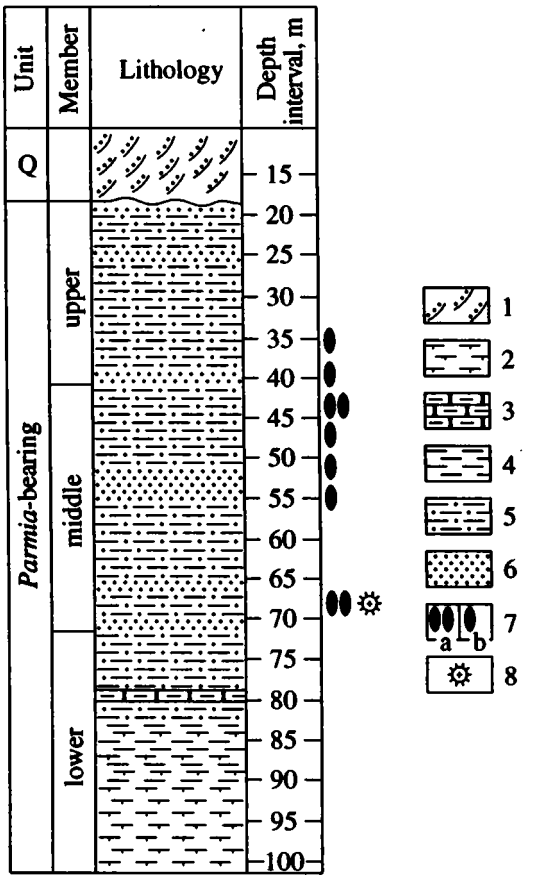


Fig. 4. Lithostratigraphy of *Parmia*-bearing unit recovered by Borehole 80. (1) Quaternary deposits; (2) siltstone with dolomitic matrix; (3) silty dolomite; (4) clayey siltstone; (5) sandy siltstone; (6) fine-grained sandstone; (7) *Parmia* remains abundant (a) and scarce (b); (8) occurrence level of Timan microbiota (organic-walled microfossils).

central Timan, where the rock successions are more complete (Solntsev, 1959; Zhuravlev and Osadchuk, 1963). The concept was considered as valid in many works of the 1960s and 1970s, some preceding the date of publication of the unified scheme (Keller, 1968; Getsen, 1970, 1988; Raaben, 1975; Chernaya *et al.*, 1979), and in others edited afterward (*Rifei i vend...*, 1987; Getsen, 1988; Getsen and Dedeev, 1990; Tereshko and Kirillin, 1990; Raaben and Oparenkova, 1997).

However, Raznitsyn (1961, 1962, 1964) argued for the reversed succession of siliciclastic and carbonate deposits. Like many others, he correlated siliciclastic rocks of the Dzhezhim Parma with the lower horizons of the Upper Riphean Karatau Group in the Urals, but considered the dolomite sequence as an analogue of the upper Middle Riphean Avzyan Formation taking into account data on bioliths determined at that time. Later, these data were revised (Zabrodin, 1968), and now the Late Riphean age of dolomite beds in question is doubtless, being substantiated by representative assemblages of stromatolites and oncolites (Raaben and Zabrodin, 1972).

At present, Olovyanishnikov believes that dolomites of the Pav'yuga Formation are the oldest rocks in the Dzhezhim Parma section. Accepting the late Late Riphean age of the formation, he places the siliciclastic rocks at higher levels corresponding to the uppermost horizons of the Upper Precambrian, namely to the Kudash and Vendian (Olovyanishnikov, 1998). In his local stratigraphic scheme, the succession of units from the base upward is as follows: Pav'yuga, Vizinga, and Dzhezhim formations.

Below, we consider these formations in the succession authorized by the unified scheme admitting, however, that the other version is also possible. The issue remains unclear, because the recent mapping at the scale 1 : 50 000 did not elucidate the direct relations between the units and showed, together with data of geophysical research, that the fault tectonics is of prime significance for understanding the Dzhezhim Parma structure.

The Vizinga Formation includes frequently alternating thin beds of the following rocks: greenish to dark gray phyllite-like shales of silty or clayey types; siltstones and fine-grained sandstones of mica–quartz, polymictic, and arkose composition, all bearing sporadic glauconite grains and having ferruginous carbonate matrix; thin intercalations of ankerite dolomites and sandy ankerite. The formation is 600–700 m thick. Its rocks are exposed within a narrow zone striking northwestward, where the beds steeply (55°) dip toward the northeast (Raznitsyn, 1961) being locally deformed into small narrow folds (Zhuravlev and Osadchuk, 1963). According to the general opinion, the northeastern boundary between the Vizinga and Pav'uyga formations is of tectonic origin. The character of the northwestern contact with the Dzhezhim Formation is not so clear. Chochiya (1955) and Vladimirskaya (1955) did not part sediments of the Vizinga Formation from the Dzhezhim sandstones, considering and mapping them together as rocks of the Rassol'nyi Formation distinguished in the Polyudov Ridge. In opinion of Raznitsyn, these were two subformations of a single stratigraphic subdivision (Dzhezhim Formation). Zhuravlev and Osadchuk (1963) attributed the Vizinga Formation to the Chetlas Group, suspecting that the Dzhezhim sandstones rest above the erosion surface of the Visinga Formation. Like Raznitsyn and some other researchers (Zhuravlev *et al.*, 1966; Raaben, 1975; Getsen and Pykhova, 1977; *Rifei i vend ...*, 1987), they attributed the Chetlas Group and Dzhezhim Formation to the Upper Riphean. The Middle Riphean age was authorized for this group and Vizinga Formation in the unified scheme on the basis of the Chetlasskii Kamen' section (Nalivkin, 1962; Volochaev *et al.*, 1967; Keller, 1968). However, former identifications of microfossils from the Chetlas Group of central Timan were seriously criticized and cannot be considered now as prov-

ing the Middle Riphean age of the group, as Olovyanishnikov (1998) stated in his historical review, considering the Visinga Formation as a provisional unit of the Dzhezhim Parma section.

The Dzhezhim Formation (Dzhezhim Sandstones in terms of Miloradovich) predominantly consists of red, brownish red, pinkish, and locally gray beds of arkose and feldspar–quartz sandstones. The sandstone beds are intercalated with interlayers of gravel, gravel-pebbly conglomerate, and flaggy siltstones with black ore laminas rich in titanium. According to Zhuravlev and Osadchuk (1963), the lower sandstone beds enclose pebbles and gravel of quartzites and schists probably indicating that they overlie the erosion surface of the Chetlas Group. In opinion of Tereshko and Kirillin, the Dzhezhim Formation rests on underlying deposits with the angular unconformity, whereas Olovyanishnikov argues for tectonic character of all formation boundaries. The formation is estimated to be either 250 (Tereshko and Kirillin, 1990) or 800 m thick (*Stratigraficheskii slovar'...*, 1994). Considering the red arkose sandstones and thin interlayers of siltstones as the only rocks of the formation, Tereshko and Kirillin apparently accepted a narrower stratigraphic range of the unit than other investigators. Olovyanishnikov distinguished two subunits of the Dzhezhim Formation: basal beds (over 200 m thick in total) of fine-grained to inequigranular red oligomictic and arkose sandstones intercalated with subordinate members of greenish gray siltstones and shales, and the upper subunit (about 300 m thick) of arkose sandstones enclosing interbeds and members of gravel, conglomerates, and quartz-mica siltstones. In his opinion, the northeastern contact between the latter and Vizinga Formation represents the reverse thrust fault.

As is shown in early maps (Raznitsyn, 1961), the Dzhezhim sandstones are in contact with rocks of the Pav'yuga Formation in the extreme northwest of their distribution zone, though the boundary type is as yet unknown. It is a common practice to consider the unit under consideration as a stratigraphic equivalent of the An'yuga Formation distinguished in other areas of Timan (*Stratigraficheskii slovar'...*, 1994). Both formations are also thought to be correlative with the Rassol'nyi Formation of the Polyudov Ridge and with the Zil'merdak Formation (totally or partly) of the Upper Riphean stratotype in the southern Urals. However, as mentioned above, Olovyanishnikov attributes the Dzhezhim and An'uyga formations to the uppermost Vendian horizons of the Upper Precambrian.

The Pav'yuga Formation of stromatolitic dolomites (or conchoidal dolomites in terms of Miloradovich, the Niz'va Formation of Chochiya and Vladimirskaya, Bystrukha Formation of Solntsev, and Bystrukha Formation of Zhuravlev and Osadchuk) characterizes rocks exposed within the northeastern zone of the Upper Precambrian complex of the Dzhezhim Parma. Exactly this zone is adjacent to the distribution area of *Parmia*-bearing deposits unexposed at the surface. The Pav'yuga Formation was originally distinguished in the central Timan. Using analogy with stratigraphic subdivisions of the Polyudov Ridge, Chochiya and Vladimirskaya mapped this unit as the Niz'va Formation that yields very similar stromatolite and microphytolith assemblages (Raaben and Oparenkova, 1997). An earlier subdivision scheme suggested by Raznitsyn (1961, 1962, 1964) was different. He distinguished instead two other units: the lower Yshkemes (later renamed as Ropcha) and upper Vapol formations correlating them both with the Middle Riphean Avzyan Formation of southern Urals. Tereshko and Kirillin (1990), who came back to this scheme and divided again the carbonate rocks of Dzhezhim Parma into the Yshkemes and Vapol formations, attributed these units, however, to the Upper Riphean. This viewpoint is shared by Bekker and, partly, by Olovyanishnikov, who considered the units as subformations of the Pavyug Formation. In opinion of the latter, the lower subunit includes the dolomite beds (apparent thickness 700–750 m) steeply dipping northeastward and exposed along the Yshkemes Creek in the following succession (from the base upward):

(1) white to light gray fine- and medium-grained quartz and quartz–feldspar sandstones (80–100 m thick);

(2) gray to dark gray stromatolitic dolomites displaying the variable degree of silicification, local brecciation, and pinkish coloration (300 m thick);

(3) dark gray, almost black dolomite with abundant calcite veins; the rock has bituminous smell when cracked (5 m thick);

(4) gray cherty "algae" dolomite locally brecciated (200 m thick);

(5) gray, clayey to sandy dolomites intercalated with members of variegated splintery shales and siltstones, and with large rare buildups of stromatolites (about 150 m thick).

In the southwest, these rocks are in tectonic contact with Paleozoic deposits and sediments of the Dzhezhim Formation. In the northeast, the Yshkemes Subformation is, according to Olovyanishnikov, in tectonic contact with the upper Vapol Subformation, whose rocks are exposed along the eponymous (or Vapolka) river and can be divided into the following subunits (from the base upward):

(1) light gray and pinkish massive dolomites bearing abundant microphytoliths and rare lentils of chert (about 150 m thick);

(2) light gray and pinkish massive stromatolitic dolomites (about 200 m thick).

The lower and upper boundaries of the subformation are unexposed. The estimated total thickness of the subformation is 570 m, according to Olovyanishnikov, and 1000 m, according to Tereshko and Kirillin (1990).

The revived Raznitsyn's concept that the dolomite beds exposed along the Yshkemes Creek and Vapol River are different in age appears to be awkward. It was disproved by studies on stromatolites and oncolites collected by Zhuravlev, Gafarov, Raaben, and Zabrodin (Zhuravlev and Osadchuk, 1963; Zabrodin, 1968; Raaben, 1969, 1987; Raaben and Zabrodin, 1972). For instance, the bed-by-bed study on microbialites (Zabrodin, 1968, pp. 41 and 42) showed that the Vapol Formation of gray and pinkish dolomites (Vapol River exposures) and the greater upper part of the Yshkemes Formation (in terms of Raznitsyn) show similar successions of identical stromatolite and oncolite assemblages. In addition to well-known stromatolite taxa correlating these units (*Inzeria djejimi* Raab., *Gymnosolen ramsay* Steinm., and *Parmites concrescens* Raab., the latter occurring at a higher level), we should mention here the characteristic form *Conophyton miloradovičі* Raab. formerly known only from the Vapol River, but later detected by Raaben in collection of Tereshko from the Yshkemes Creek. These data discredit the idea of Olovyanishnikov that dolomite beds of the Yshkemes Creek and Vapol River localities represent successive formations or subformations changing upward one another.

Accepting the former nomenclature, Bekker suggests to revise scopes of the units. He places the lower boundary of the Vapol Formation at the first occurrence level of *Gymnosolen* buildups below the beds bearing abundant stromatolites and enclosing the member with cherty nodules. In this case, the lower unit turns out to be corresponding only to remaining dark-colored stromatolitic dolomites that represents the Yshkemes Formation proper in terms of Raznitsyn (1961, p. 431). It remains unclear, however, how these dolomites fit the formation description given by Tereshko and Kirillin (1990, p. 81): "... the formation rocks are mostly represented by red dolomites, which are clayey, horizontally laminated at the base, grading into stromatolitic varieties higher in the section, and enclosing siltstone interlayers in the uppermost part." This question is important and related to the suggestion that the Dzhezhim Parma section may include an analogue of the Demino Formation of the Polyudov Ridge. According to Bekker, this could be the Yshkemes Formation in its newly accepted scope. Actually, if the clayey dolomites with parallel lamination, which were formerly unknown in the Yshkemes Creek section, are the rocks discovered for the first time by mapping geologists of the Vychegda Expedition, they may be considered as analogues of the Demino Formation rocks, though Vladimirskaya (1955) unsuccessfully searched for them in the Dzhezhim Parma area. We should add as well that neither stromatolites characteristic of the Demino Formation of the Polyudov Ridge, the Katav Formation of southern Urals, or Vorykva Formation of the Chetlas–Tsil'ma zone of Timan, nor stromatolites typical of the basal Pav'yuga beds in the Tsil'menskii Kamen' site and correlating the beds with the Podinzer Formation of the stratotype (in other words with the Sim Horizon) have been met in paleontological collections from the Dzhezhim Parma area (Raaben and Oparenkova, 1997). All stromatolites and microphytolith assemblages known from exposures of the Vapol River, Yshkemes and Vil' creeks are characteristic of the Upper Karatavian (Min'yar, Tangaur). Their occurrence levels well correspond to the Minka and B'yanka members of the Min'yar Formation in the stratotype, and also to subformations II and III of the Niz'va Formation in the Polyudov Ridge. The biolith-bearing analogues of uppermost beds of the Min'yar Formation, in particular, of the Shubino Member lacking cherts and of the Uk Formation, are unknown anywhere in the Timan Ridge. In the Polyudov Ridge, they are distinguished in a very tentative manner (*Stratotip...*, 1983).

In opinion of two of us, named below, the *Parmia*-bearing unit corresponds exactly to this stratigraphic interval lacking the microbialite characteristics. Bekker (1999) correlates the unit with the Uk Formation of the Upper Riphean stratotype, i.e., with the Tam'yan (= Kudash) Horizon, whereas Olovyanishnikov considers it as a structural and stratigraphic analogue of the Paun Formation in central Timan. As we will see below, both assumptions contradict paleontological characteristics of the *Parmia*-bearing deposits that yield, in addition to annelidomorphs, the organic-walled microfossils typical not of the upper, but of the lower Karatavian levels.

TIMAN MICROBIOTA FROM *PARMIA*-BEARING DEPOSITS

Materials and investigation procedure. The studied microfossils are macerated from a single core sample, where *Parmia* remains were distinguished (Borehole 80, depth interval of 70.0–69,2 m). At the Geological Institute, Russian Academy of Sciences (GJN RAS), Moscow, N.G. Vorob'eva and A.F. Veis subjected to laboratory treatment the greater part of the sample (about 500 g), whereas its other part (about 300 g) was studied by T.N. German at the Institute of Precambrian Geology and Geochronology (IPGG RAS), St. Petersburg. The careful analysis of the rock bearing the unique *Parmia* remains included three subsequent stages: (1) rock decomposition in concentrated HF; (2) selection of largest forms most complex in morphology under the binocular microscope; (3) centrifuging of unsolvable residue after selection in the heavy liquid M-45, specific weight 2.1–2.2 g/cm^3. As a result, over 40 preparations were obtained and studied under microscope at both institutions. Several hundreds of organic-walled microfossils distinguished in preparations are colored yellow or orange-yellow being fairly well preserved despite the noticeable corrosion of their envelopes. It should be noted that determinations obtained at different institutions are perfectly compatible and confident, as the researchers involved in the work hold the same opinion on the nature and classifi-

cation of Precambrian microfossils (German, 1990; Veis, 1993; Veis and Vorob'eva, 1993).

Composition of the Timan microbiota. The representative assemblage of recognized microorganisms includes, in addition to very common long-ranging elements of various Precambrian microbiotas, some microfossils of a limited time range and geographic distribution. All the specimens characterize 27 genera and 31 species of different morphotypes. Moreover, there were distinguished some morphotypes, which may represent other Precambrian taxa, though they are different from the known type species of the taxa by their abnormal dimensions. Some of them cannot be identified with confidence because of the fragmentary state of remains. In general, acritarchs (8 genera and 9 species) and filamentous sheaths (8 genera and 10 species) are most abundant in the studied assemblage (more than 70% of all identified taxa). Less abundant in the microbiota are colonial coccoidal microorganisms (2 genera, 3 species, and 8% of all taxa), trichome-like fossils (3 genera, 3 species, and 8% of all taxa), and forms of complex morphology (6 genera, 6 species, and 14% of all taxa). We tentatively included in the last group the widespread and clearly diagnosable *Parmia* cuticles, and this explains the relatively high content of complex morphotypes in the assemblage.

Acritarchs of the Timan microbiota are mainly represented by relatively simple sphaeromorphic *Leiosphaeridia* and *Chuaria*, whose envelopes vary in size from 10–20 to 280 μm in the first case and from 320 to 1500 μm in the second.[1] The first genus includes three species: *L. crassa* (Naum.), *L. obsuleta* (Naum.), and *L. jacutica* (Tim.), whereas the only species *Chuaria circularis* Walc., emend. Vidal et Ford, represents the second taxon. The size peaks correspond to 20, 140–150, and 240–260 μm for *Leiosphaeridia* forms, and to 320, 450, and 520 μm for *Chuaria* specimens. In addition to these dominant taxa of simple acritarch, the group includes envelopes with inner bodies that are classified as *Nucellosphaeridium nordium* (Tim.) and vary in size from 60 to 570 μm. In preparations, smaller representatives of the latter (60–190 μm) occur together with tiny *Leiosphaeridia* specimens (50 μm) either as isolated vesicles, or as components of subspheroidal coenobiums. Marginate and acanthomorphic acritarchs are less abundant, but important components of the group. The marginate forms are represented by typical *Simia nerjuenica* A. Weiss (outer diameter 280–380 μm) and by unusual *Simia* sp. with irregular outer contour (diameter up to 160 μm). Acanthomorphic acritarchs belong to three taxa: spheroidal *Trachyhystrichosphaera aimica* Herm. (diameter up to 375 μm) having small spine-like processes and lacking outer membrane; *T. stricta* Herm. (210–380 μm across) having elongated tubular processes and wide margin; and ellipsoid *Prolatoforma aculeate* Mikh. (300 × 250 μm in dimension) displaying the bipolar position of tiny conical processes surrounded by frill. In addition, we distinguished single specimens of large oval vesicles similar to *Navifusa* (up to 200 × 520 μm in size).

Filamentous sheaths represent another important group of the microbiota under consideration. Among them, we distinguished six principal morphotypes: (1) most simple tubular *Eomycetopsis robusta* Schopf, emend. Knoll et Golubic (2–4 μm wide) occasionally composing mat-like aggregates together with *Leiotrichoides typicus* Herm., emend. Herm (8–20 μm wide), *L. gracilis* Pjat. (20–32 μm), and *Asperatofilum experatus* Herm. (40–42 and 56–58 μm); (2) multiserial aggregates of *Polytrichoides lineatus* Herm., emend. Herm. representing one of most characteristic morphotypes of the assemblage (individual filaments up to 10 μm wide and aggregates wider that 40 μm); (3) glomerular sheaths of *Glomovertella glomerata* (Jank.) with filaments up to 6 μm wide; (4) broad (up to 32–34 μm) thin-walled stiganema-like sheaths with distinct lateral branching, which are lacking their internal content in general, but sometimes enclose multiserial chain-like aggregates of small (4–6 μm) coccoidal cells; (5) taeniate microfossils (up to 340 μm wide) displaying fine transverse striation and similar to *Plicatidium latum* Jank.; (6) large (160 × 34 μm) elongated ellipsoid *Archaeoellipsoides grandis* (Hofmann), the most peculiar sheaths of microbiota presumably representing akinetes of hormogonian cyanobacteria, and *A. major* (Golovenok et Belova) similar in morphology, but much smaller in size (34 × 16 μm).

Representatives of other morphological groups of the microbiota are considerably less diverse and abundant than acritarchs and sheaths. Colonial coccoidal forms constitute fragments of thalluses of *Ostiana microcystis* Herm. consisting of two size groupings (cell diameters 18 and 24–26 μm), and also occuras small colonies of *Myxococcoides minor* Schopf (cells 8–10 μm across) and *M. grandis* Horodyski et Donaldson (cell size up to 30, and even to 50 μm). Moniliform *Trachytrichoides ovalis* Hermann (30 × 60 μm in size), *Arctacellularia sphaerica* Pjat. (cells 30–34 μm wide and 40–50 μm long), and very large septate thalluses of *Segmentothallus asperus* Herm. (more than 500 μm wide) are characteristic trichome-like forms, among which two first species have sometimes small inner inclusions. Forms of complex morphology are more diverse and represented by the following taxa: envelopes *Caudosphaera expansa* Herm. (up to 390 μm in diameter) and *Germinosphaera guttaformis* Mikh. (150–200 μm in diameter), both having isolated processes to 140 and 200 μm long, respectively; thin tubules of volumetric-spiral *Elatera binata* Hermann (120 μm wide) that have characteristic rhombic orna-

[1] Classification of microfossils distinguished here corresponds to that published in the book "Mikrofossilii dokembriya SSSR" (Precambrian Microfossils of the USSR) of 1988. Species composition of the Timan microbiota is discussed in the text and illustrated in Plates I and II.

mentation;[2] fragments of large articulated *Eosolena loculosa* Hermann (to 260 μm long and incomplete fragments over 100 μm wide); trilobate thalluses similar to *Majaphyton antiquaum* Tim. et Herm. (maximum dimensions of fragments to 280 μm).

Some organic remains from the Timan microbiota are abnormally large, and their taxonomic position is defined with certain reservations. These are curved fusiform vesicles displaying distinct transverse striation and resembling acritarchs *Cucumiforma* (60 × 300 μm), sheaths with coarse transverse ribbing ex gr. *Rectia costata* (Jank.) that are up to 120 μm wide; and elongated envelopes of irregular fusiform shape that are similar to *Brevitrichoides tiulmenicus* Jank. et Kozl. (100 × 420 μm).

Paleoecology of the Timan microbiota and *Parmia* remains. All *Parmia* specimens known at present occur within a narrow stratigraphic interval of a single borehole. Consequently, sedimentological indicators may hardly be used for understanding facies–ecologic environments favorable for these fossils. However, microbiota from the same interval elucidates the issue to certain extent.

Study of several Riphean reference sections in Siberia revealed principal features of the lateral distribution of different microorganisms in the basins of that time (Veis and Petrov, 1994; Veis *et al.*, 1998a, 1998b). As is shown, there was a uniform style of facies–ecologic distribution of microbiota across shelf zones of the Riphean marine basins, where four taxonomic groupings of microorganisms (deep-water, medium-deep or "optimal," transitional, and shallow-water) regularly replaced one another along the basin profile. The "optimal" and shallow-water groupings turned out to be most contrast in composition. The former typical of lower subtidal and proximal shelf zones included large and complex morphotypes, mostly benthic eucaryotes, whereas the latter characteristic mainly of the upper subtidal zone, but also known from intertidal settings, predominantly included small and simple planktonic organisms or assemblages of mat-forming prokaryotes. In deeper settings of distal shelf, the microbiota composition was noticeably different, and destructive microorganisms decomposing organic matter were dominant here. In general, these results revealed main factors that controlled the lateral distribution of microorganisms. These were the basin depth, intensity of hydrodynamics in various facies–ecologic zones of Riphean basins, and position of microbiotas on the transgressive–regressive trends of the basin evolution.

After comparison of Timan microbiota with other representative Riphean assemblages of microorganisms, whose position in the paleofacies profile is established, we are sure that microfossils associated with *Parmia* represent an "optimal" (medium-deep) grouping of Riphean microorganisms. This is evident from a wide spectrum of morphotypes present in the Timan microbiota and characteristic of that grouping. These are the following taxa: giant *Chuaria*; marginate *Simia*; acanthomorphic *Trachyhystrichosphaera* and *Prolatoforma*; thalluses of coccoidal *Ostiana*; sheaths of *Polytrichoides, Rectia*, and *Plicatidium*; trichome-like *Trachytrichoides* and *Arctacellularia*; complex *Elatera, Eosolena, Majaphyton*, and some other indicative forms. In the well-studied Riphean sections in Siberia, microfossil assemblages like this are known only from sediments accumulated in lower subtidal settings and proximal shelf zones below the storm wave base (at the depth of few dozens of meters). As an exception, some components of "optimal" groupings of Riphean microorganisms migrated in shallower settings of the upper subtidal zone, the usual habitat areas of shallow-water and/or transitional groupings. These episodic migrations were controlled by appearance of specific quiet-water setting in the semi-isolated inner shelf, or in specific contrast elements of relief (Petrov and Veis, 1995). Having no other data constraining the distribution area of *Parmia* remains, we consider them as dwellers of the medium-deep zone of the Vychegda paleobasin.

Position of Timan microbiota in the Riphean–Vendian succession of microfossils and age of *Parmia*. Current viewpoints on evolutionary transformations of Late Precambrian microbiotas (Riphean, in particular) are controversial, as there are two different approaches to the problem, each independently based either on biostratigraphic, or on chronometric (geochronological) data. In terms of biostratigraphic approach, the general succession of microbiotas is thought to be inferable from its really observed and compatible regional fragments. Microbiotas from the Riphean and Vendian type sections are accepted as playing the key part in this case. Taxonomic similarity of microbiotas characterizing the above fragments and succession of comparable changes in the composition are regarded as the basis for correlating the microfossil-bearing sections in different geographic regions and modeling transformations in the Late Proterozoic microcosm (Keller and Yankauskas, 1980; Mikhailova, 1985; Pyatiletov, 1988; Vidal *et al.*, 1993; Golovenok and Belova, 1995; Burzin, 1995; Sokolov, 1998; Veis *et al.*, 1998a).

Solving the same problem, adherents of the chronometric approach take into consideration not the microphytological data (paleontological, in general), but primarily the results of isotopic dating and chemostratigraphy of the host rocks (*Earth's Earliest...*, 1983; *Proterozoic Biosphaere...*, 1992; Semikhatov, 1993, 1995; Knoll, 1994; Knoll and Sergeev, 1995; Xiao *et al.*, 1997). In this approach, composition of microbiotas is not of prime significance for placing them into the general vertical succession that is graduated in units of the Meso- and Neoproterozoic chronometric scales (Plumb, 1991). It is remarkable that the reconstructed paleontological successions may be based in this case not only on discrete microbiotas, but even on single

[2] Minor *Elatera* fragments with rhombic ornamentation resemble sheaths of the genus *Pomoria* Sivertseva and were classes with the latter at the initial investigation stage of the Timan microbiota (Tereshko and Kirillin, 1990).

representatives of microfossils. It is unimportant as well that the scale subdivisions may lack stratotypes. The difference between two approaches is far from being of no concern, because the age estimates for many representative microbiotas are so discordant now that all the experience of microphytological studies is called into question. As we will see below, the issue is also of prime significance for determination of stratigraphic position of the Timan microbiota coexisting with *Parmia*.

In terms of biostratigraphy, the microbiota under consideration includes taxa of two categories: (1) those limited in distribution by the Late Riphean–Vendian interval, and (2) Precambrian microfossils of wide stratigraphic ranges. We should mention that compositions of both groups of taxa, when interpreted on the basis of chronometric and biostratigraphic models, considerably change (in the first case, the number of transit taxa increases, whereas the list of taxa important in stratigraphic aspect becomes much smaller). This does not concern, however, the most simple transit forms present in the Timan microbiota, namely, the acritarchs *Leiosphaeridia* and *Nucellosphaeridium* or sheaths of *Eomycetopsis, Leiotrichoides*, and *Archaeoellipsoides*, as well as colonial coccoidal *Myxococcoides*, all known from various Precambrian microbiotas different in age. The other case is when we consider *Trachyhystrichosphaera, Prolatoforma, Chuaria, Simia, Ostiana, Asperatofilum, Polytrichoides, Rectia, Plicatidium, Caudosphaera, Glomovertella, Elatera, Eosolena, Trachytrichoides*, and *Arctacellularia*, the morphotypes very characteristic of the Timan microbiota.

At present, the Late Riphean of southern Urals and central Siberia is characterized by three successive assemblages of microfossils: the Kerpyl' (Bezymyannyi) assemblage that formerly had no analogues in the southern Urals;[3] the Lakhanda (or Derevnya, Bederysh) microbiota; and the Miroedikha assemblage known from the Turukhansk Uplift (Veis, 1988; Veis *et al.*, 1998a, 1998b; Pyatiletov, 1988). Large acanthomorphic *Prolatoforma* and *Trachyhystrichosphaera* species present in the Timan microbiota exclude a possibility to correlate it with the Kerpyl' assemblage. The Lakhanda assemblage appears to be most similar to the microbiota in question, as it comprises all characteristic taxa of the latter, including the very peculiar stiganema-like branching filaments and *Segmentothallus* that are missing from the Miroedikha microbiota. In addition, the Timan and Lakhanda microbiotas lack several taxa typical of the Miroedikha assemblage, such as *Polysphaeroides filiformis* Herm., *Palaeolyngbya sphaerocephala* Herm. et Pyl., and some complex forms (German, 1990; Veis and Vorob'eva, 1998; Veis *et al.*, 1998b). Accordingly, we conclude that the only biostratigraphic analogue of the Timan microbiota is that from the Lakhanda (Bederysh) Formation.

As for the suggested Vendian age of the *Parmia*-bearing deposits (Tereshko and Kirillin, 1990), the idea is completely discredited by the taxonomic composition of coexisting microfossils. Among all morphotypes distinguished in the Timan microbiota, only *Chuaria, Ostiana, Glomovertella, Asperatofilum*, and *Polytrichoides* occur, presumably together with *Arctacellularia* and *Trachytrichoides*, at the Redkino–Kotlin and correlative levels of the Upper Vendian (Velikanov *et al.*, 1983; *Vendskaya sistema...*, 1985; *Mikrofossilii...*, 1998; Burzin, 1996). It is necessary to take into account as well that the above taxa are extremely rare in the Upper Vendian deposits of Russian platform and adjacent regions, where they coexist with very indicative taxa (*Pomoria, Cochleatina, Striatella, Vendomyces*, and some others), none of which was detected in the *Parmia*-bearing sediments. It is likely improbable to attribute the Timan microbiota to the Early Vendian, because this level is poor in microfossils in some areas and yields very specific acanthomorphs, like *Echinosphaeridium, Ericiasphaera*, and *Briareus*, in the others (Zang and Walter, 1992; Burzin, 1996). Thus, we are left with only one possibility to consider the Timan microbiota and coexisting *Parmia* specimens as corresponding in age to the Bederysh or Lakhanda level of the lower Upper Riphean.

The comparative analysis of the Timan and all other Precambrian microbiotas known outside Russia was not an objective of this work, since the latter are described very well in a series of recent publications (for review and bibliography, see *Mikrofossilii...*, 1989; *Proterozoic Biosphaere...*, 1992; Semikhatov, 1991; Knoll, 1994, 1995; Hofmann and Jackson, 1994; Vidal and Moczydlowska, 1997). We consider as actual the comparison of microfossils from Timan with the Huainan microbiota known from the North Chinese platform. This microbiota is widespread in the eponymous district of the Anhui Province of China (Sun and Hou, 1987; Vidal and Moczydlowska, 1997; Zang and Walter, 1992; Yin and Sun, 1994). This is actual because the microbiota from China either coexists, or occurs immediately below beds that yield remains of worm-like organisms classed with genera *Sinosabellidites, Protoarenicola*, and *Pararenicola* (Sun, 1986; Gnilovskaya, 1998). These taxa are similar to *Parmia*, and the problem of their age relations is of particular interest.

Leaving aside other details, we should mention that the representative assemblage of organic-walled microfossils (more than 20 species of 20 genera) was recovered, together with *Sinosabellidites* remains, only from the Liulaobei Formation of China, the fourth one from the base among seven formations distinguished in the Huainan and Feishui groups of the Anhui Province (Zang and Walter, 1992, and references therein). In

[3] Some characteristic taxa of the assemblage are now detected in the Nugush Subformation of the Zil'merdak Formation in the Karatavian type section (Veis and Larionov, 1999; Veis *et al.*, 2000).

addition, the bedding planes in this and Jiuliqiao formations (the latter is sixth from the base and poor in microfossils, though bearing abundant *Protoarenicola* and *Pararenicola* remains most similar to those of *Parmia*) are marked by round and oval impressions that are abundant, fairly large, and resembling those of *Chuaria* and *Tawuia*. Since the *Chuaria–Tawuia* association is untypical of the Timan microbiota, and because of very disputable biological relations and stratigraphic significance of the pair (see Steiner, 1996, for discussion and bibliography), we focused our attention only on the comparison of the organic-walled microfossils from the Timan and Huainan microbiotas.

Both microbiotas include only few similar or identical varieties of *Simia* and *Rectia* typical of the Late Riphean. The associated scarce *Polytrichoides* and *Glomovertella* are limited in vertical distribution by the Upper Riphean–Upper Vendian, while abundant *Eomycetopsis, Myxococcoides, Leiosphaeridia*, and some other species that transit for the Riphean. As for other microfossils of the Huainan microbiota from the Liulaobei Formation, they are classified in the microphytological nomenclature that is out of use in Russia and can be correctly compared with taxa of the Timan assemblage only after a special monograph study. Nevertheless, it is clear that many representative Timan morphotypes of different structure are missing from the Liulaobei Formation, for instance, *Prolatoforma, Trachyhystrichosphaera, Ostiana, Archaeoellipsoides, Asperatofilum, Trachytrichoides, Arctacellularia, Majaphyton, Segmentothallus*, and *Plicatidium*. At the same time, the Timan microbiota lacks some Chinese forms, among which *Baltisphaeridium, Ambiguaspora*, and *Melanocyrillum* are most important.

Three last taxa from the Liulaobei Formation are widespread only in the upper Upper Riphean, Vendian, and/or Lower Cambrian, and this could be considered as an indication of a younger age of the Chinese microbiota as compared to that of the Timan Ridge. However, such a conclusion can be taken for the very preliminary one. In opinion of N.A. Volkova (personal communication of 1996), *Baltisphaeridium* forms from the Liulaobei Formation differ from the described Late Precambrian and Early Paleozoic acanthomorphic acritarchs, and some other researchers (Yin and Sun, 1994) consider them as contaminants. Moreover, the tetrad scar in sphaeromorphic envelopes is now not always thought to be important for taxonomic classification and cannot be considered as stratigraphically important indication (Knoll and Golubic, 1979). Similarly problematic are rare vase-shaped fossils tentatively attributed by Zang and Walter (1992) to the genus *Melanocyrillium*. Since the Liulaobei Formation lacks other indicative microfossil taxa, its age cannot be identified correctly, and correlation between the Huainan and Timan microbiotas on the basis of microphytological data alone remains disputable. The problem can be solved, when additional data of geology and paleobiology will be available for consideration.

METAZOA FROM THE TIMAN AND HUAINAN REGIONS

Annelodomorphs from the Timan

Presented below are expanded characteristics of the monotypic genus *Parmia*. In accordance with our understanding of the genus nature, the description is given in terms applicable to annelids.

Family Protoarenicolidae Hofmann, 1994

Genus *Parmia* Gnilovskaya, 1998

Genus name is derived from the word "Parma," the local name for forest-overgrown elevations in the Timan Ridge.

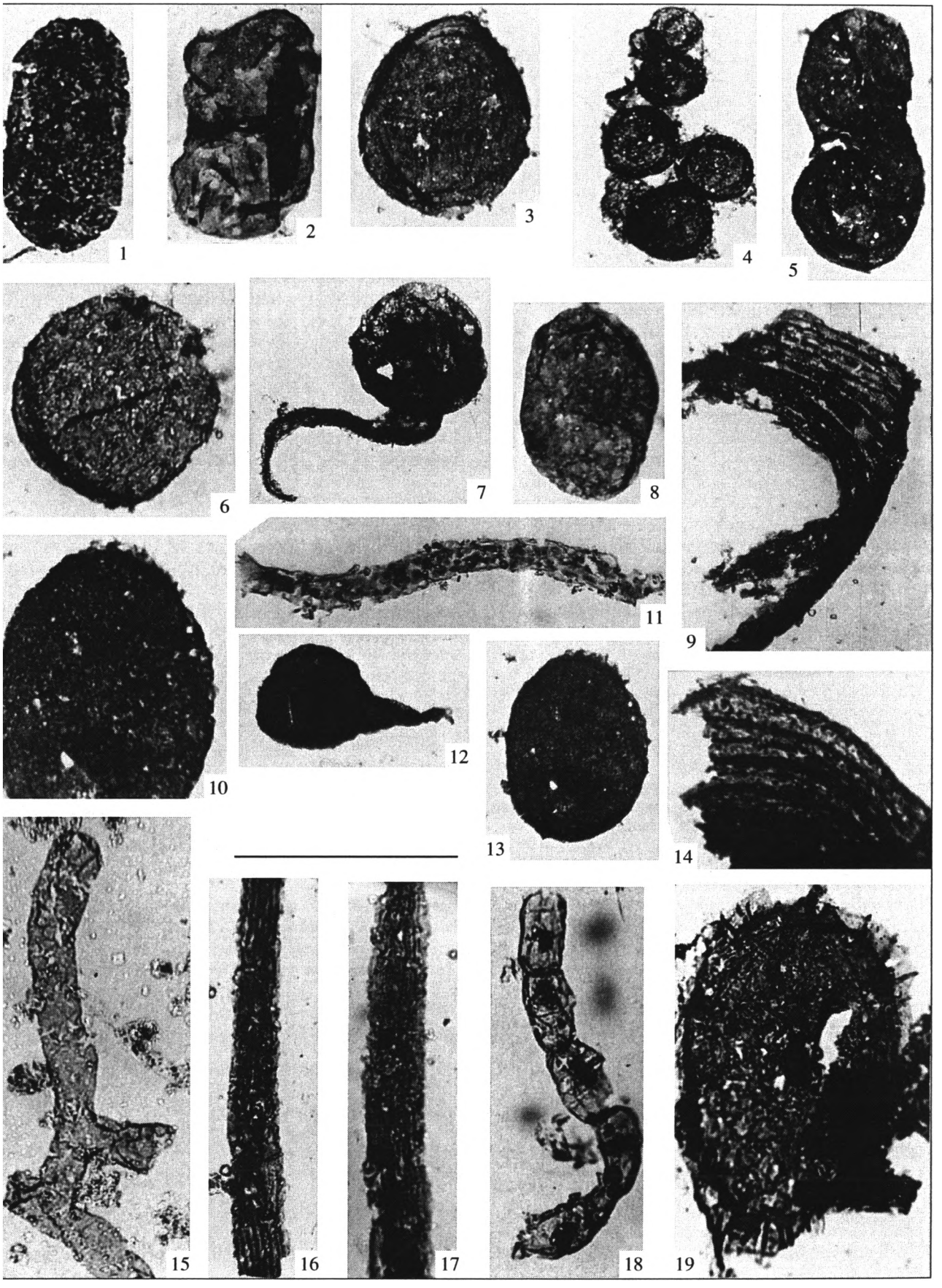
Type species: *P. anastassiae* Gnilovskaya, 1998; Russia, southern Timan Ridge, Dzhezhim Parma locality, Borehole 80, depth interval 37.5–70.0 m; Upper Riphean, *Parmia*-bearing unit.

Diagnosis. The worm-like compressed tubular body has closed elongated-rounded endings. The endings lack structural elements. The elastic cuticle is free of sculpture. Annulated structures and longitudinal cords presumably demarcate the musculo-cutaneous structure. The body is homonomously metamerized. Commissures between metameres are distinct and straight. Metameres are 10–12 times wider than long. From 5 to 11, usually 7 metameres are distinguishable per 1 mm of the body length.

Species composition. The genus is monotypic.

Comparison. Genus *Parmia* is very similar to the genus *Pararenicola* Wang, 1982, from the Jiuliqiao Formation (Sinian System) of the Anhui Province, China. Both organisms have homonomously metamerized bodies with cuticle lacking sculpture. However, *Parmia* has no proboscis-like process in the anterior endings of the body that is characteristic of *Pararenicola* morphotypes. Another distinctive feature of *Parmia* is represented by longitudinal cords unknown in *Pararenicola* and presumably delineating the corresponding muscular system. As compared to that of *Pararenicola*, the *Parmia* cuticle is much more elastic, suitable for plication. Almost the same features differ *Parmia* from *Protoarenicola*. Amount of metameres per 1 mm of the body length is comparable in all three genera: 5–11 for *Parmia*, 8–16 for *Pararenicola*, and 12 for *Protoarenicola*. Thus, metamerization of *Parmia* is slightly less frequent than that of the others.

In the fossil state, *Parmia* represents remains of the musculo-cutaneous sac, i.e., of the body proper, but not the protective tubular receptacle of organisms that is typical of representatives of families Saarinidae (*Saarina* Sokolov, 1965) and Sabelliditidae (*Sabellidites* Yanichevsky, 1926, *Parasabellidites* Sokolov, 1965, and *Sokoloviina* Kirjanov, 1968). This distinction is additionally considered in the section devoted to the Huainan biota of China.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

Parmia anastassiae Gnilovskaya, 1998

Plate III, figs. 1–5, 7, and 8

Species name is derived from the Russian woman name Anastasiya.

Holotype: IPGG RAS, specimen no. 70-2a-b; Russia, southern Timan, Dzhezhim Parma, Borehole 80, depth level 70 m; Upper Riphean, *Parmia*-bearing unit.

Paratype: IPGG RAS, specimen no. 70-2b-a; the same locality and age.

Description. Fossil organism represents a mummified musculo-cutaneous sac. Its body has a worm-like shape (Plate III, fig. 2) and is compressed-tubular in the fossil state. Cross section at the lifetime was round (Plate III, fig. 3). As a rule, the body is gently bent, sometimes in half (Plate III, fig. 1), but always without breaking of its cuticle. Endings of the body are usually not preserved, however, twelve of 83 studied specimens have one of them retained (Plate III, fig. 3). Endings are flattened-rounded, or rounded-elongated; the only specimen that has two endings preserved demonstrates the same difference (Plate III, fig. 1). By analogy with recent annelids, the flat and elongated endings may correspond to the anterior and rounded ones to the posterior parts of organism. Both endings lack structural elements. The fully preserved specimen is about 20 mm long, and its posterior part was presumably mummified at the moment of peristaltic muscular contraction. The longest (about 60 mm) specimen has only one ending preserved. The body width in different specimens varies from 1 to 2.5 mm, and one specimen can be 1.1–2 times narrower or wider in its different parts.

All bodies are homonomously metamerized (Plate III, figs. 4 and 5) except their extreme endings, where metameres (segments) are often indistinct. Some endings bear subconcentric folds originated by body contortion during the burial, when the body originally cylindrical was flattened to a variable extent. Some bodies are preserved in the three-dimension state with metameres and distinct commissures between them producing the wavy surface (Plate III, figs. 4 and 5). Some bodies are flattened to the filmy state and lack any relief (Plate III, fig. 8).

Metameres are separated one from another by distinct flat or slightly concave (convex) commissures (Plate III, fig. 7). If a body is flattened incompletely, the commissures look like narrow grooves (or narrow ribs in impressions); otherwise they resemble thin lines. When the "upper" surface of the body is displaced relative to the "lower" one during the burial, the commissure lines turn into narrow ovals.

Lateral body sides are wavy, because the corresponding sides of metameres are slightly convex. Along the long axis of the body, the length of metameres is fairly constant, 0.14 mm in average. Metameres of some specimens are narrower, to 0.05–0.09 mm. In particular parts of bodies, metameres could be as long as 0.28–0.50 mm, and these parts were presumably buried in the state of peristaltic motion. The width to length ratio of metameres is 10–12 in average and varies from 7 to 19 in different specimens. Thus, the organisms had seven metameres in average per 1 mm of their length, and amount of these elements increased to 11 or decreased to 2–4 depending on the peristaltic muscular contractions

Plate I. Microfossils from the Upper Precambrian *Parmia*-bearing deposits of Timan, Dzhezhim Parma site, Borehole 80, depth interval of 70.0–69.2 m. All pictured specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow. Scale bars are as follows: 140 μm for figs. 1 and18; 300 μm for figs. 2, 5, 8, and 10; 600 μm for fig. 3; 400 μm for figs. 4 and 12; 680 μm for fig. 6; 340 μm for fig. 7; 800 μm for fig. 9; 220 μm for fig. 11; 430 μm for fig. 13; 700 μm for fig. 14; 150 μm for figs. 15–17 and 19.

(1) *Navifusa* sp., medium-sized ellipsoid sheaths, specimen no. 123-104.

(2, 5) *Leiosphaeridia* sp., sheaths unseparated by division: (2) specimen no. 800-802; (5) specimen no. 800-191.

(3, 6) *Chuaria circularis* Walcott, emend Vidal et Ford: (3) specimen no. 123-400; (6) specimen no. 123-200.

(4) *Simia* sp., clustered sheaths variable in size and displaying characteristic peripheral fold, specimen no. 800-141.

(7) *Caudosphaera expansa* Herm. et Tim., round sheaths with long processes narrowing at the ends (presumable reproductive structures of ancient algae or fungi), specimen no. 123-610.

(8) *Leiosphaeridia jacutica* (Tim.), specimen no. 800899.

(9, 14) *Parmia anastassiae* Gnilovskaya, integument fragments of wormlike organisms: (9) specimen no. 123-511; (14) specimen no. 123-501.

(10, 13) *Prolatoforma aculeate* Mikh., ellipsoid sheath with short processes and pellicular fringe fragments preserved at one pole, specimen no. 123-204; (10) magnified fragment.

(11) *Polysphaeroides* sp., fine filamentous envelope with abundant coccoidal cells scattered at random, specimen no. 123-103.

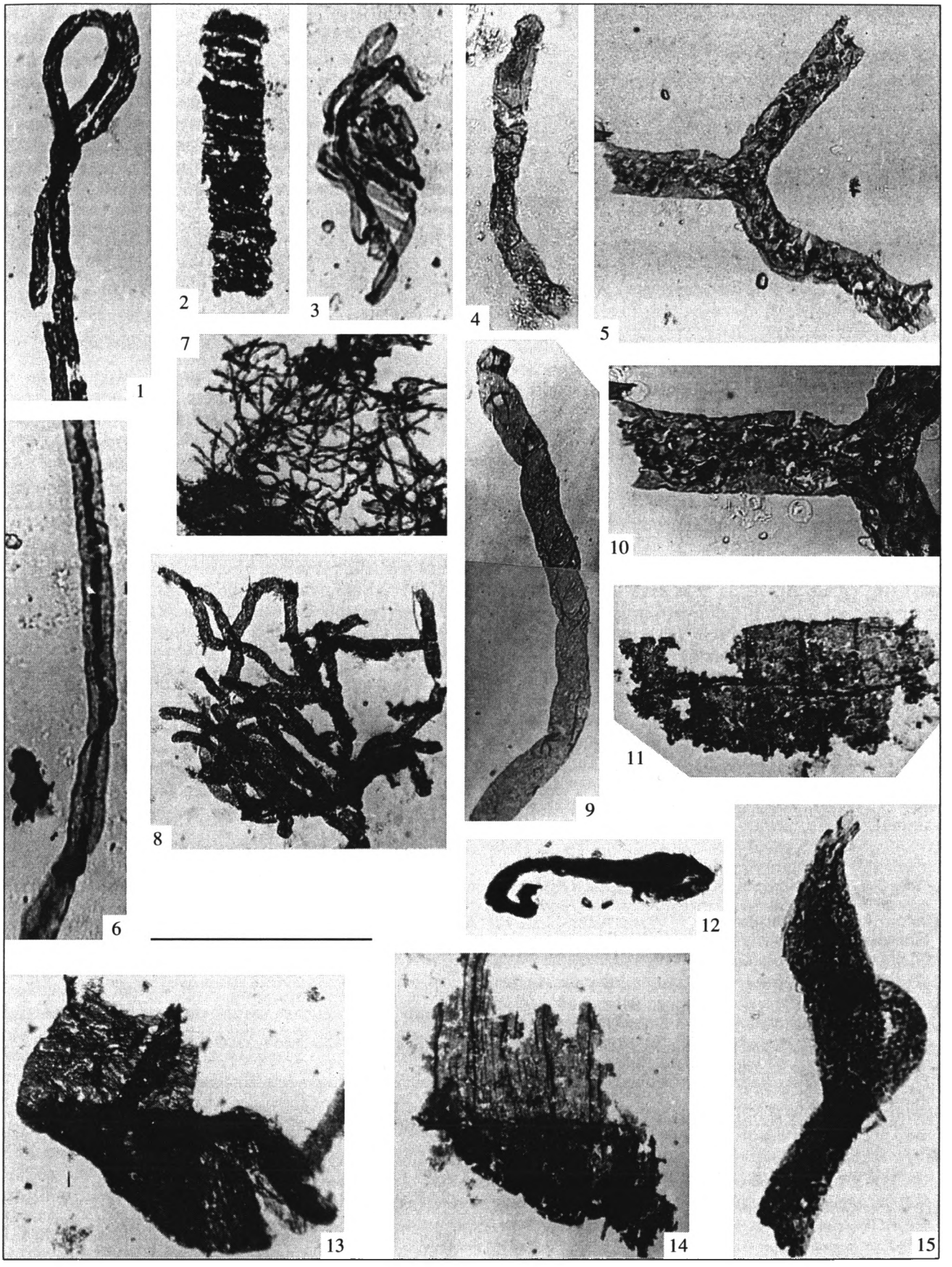
(12) *Germinosphaera guttaformis* Mikh., specimen no. 123-299.

(15) Thin-walled filamentous remains (thalluses or envelopes) distinctly ramified and lacking cells inside, specimen no. 123-621.

(16, 17) *Polytrichoides lineatus* Herm., emend. Herm., filamentous aggregates of multiserial sheaths: (16) specimen no.123-500; (17) specimen no.123-300.

(18) *Trachytrichoides ovalis* Herm., linear aggregate of large rounded-rectangular cells with dark inner inclusions (remains of collapsed cytoplasm), specimen no. 800-816.

(19) *Trachyhystrichosphaera stricta* Herm., oval envelope with elongated conic processes immersed in thin pellicular fringe, specimen no. 800-801.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

and relaxations. We also frequently observed 3 to 5 very thin transverse line of unclear origin, which cross the metamere surface between two commissures.

Within the well-preserved body areas, the surface is black and shining, as if it is carbonaceous. By analogy with recent annelids, we consider this surface as the carbonificated cuticle of the musculo-cutaneous sac. If the body is incompletely flattened, its metamerization is well seen owing to convex metamere sides and narrow concaveness between the metameres (Plate III, figs. 4, 5). In the other case, when the body is flattened completely, but cuticle is well preserved, the metamerization is emphasized by tiny hair-like conjunction lines (Plate III, fig. 8).

When the cuticular layer is destroyed, the body metamerization becomes very distinct because of the uniform type of cuticle destruction and the color contrast between the black cuticle and light background of the rock. As a rule, cuticle is preserved only in the commissure grooves between metameres, and looks like distinct black lines (Plate III, fig. 8). Exactly these lines are best preserved and represent one of remarkable morphological features. In other cases, when cuticle is preserved on lateral convex sides of metameres (Plate III, fig.4), it is seen either as black semicircles, or as thin falciform lines. Quite frequently, both types of cuticle preservation occur in combination being responsible for the distinctly metamerized aspect of the body with wavy lateral sides. Finally, cuticular remains can be occasionally preserved as fastened to the longitudinal cords extending all along the body length (Plate III, fig. 2). The cords are 0.25–0.35 mm wide, and, by analogy with recent annelids, they may be considered as elements of the longitudinal muscular system that enforced, together with annulated muscules of metameres, the peristaltic motion of the body.

Variability. The body shape is highly variable that probably indicates the organism ability to peristaltic movements. The surface aspect of fossils is also changeable depending on the body preservation state (volumetric or flattened) and on the disintegration extent of the external cuticular layer. Despite all these factors, the metamerized structure of the body is always distinct.

Material. The type collection includes 83 specimens from the type locality, 20 of which are perfectly preserved, and one has two natural endings.

Investigation History of the Huainan Biota

Data on worm-like fossils from the Huainan biota of China that was recovered from the Upper Riphean deposits turned out to be very helpful for understanding the nature of the described *Parmia* Gnilovskaya, 1998. It was a world-wide sensation, when Chinese scientists discovered in 1962 the biota in the Anhui Province, and scientific interest, as the biota investigation advanced, steadily grew. The worm-like fossils present in the biota and considered as oldest pre-Ediacarian Metazoa are of particular interest. The results of their study during 30 years are published mostly in Chinese thus being hardly accessible for Russian readers, and we decided to present here our review of publications and their critical analysis.

Carbonaceous remains of macro-organisms flattened to the filmy state and termed as the Huainan biota were recovered in 1962 from the Liulaobei Formation of the Huainan Group that is attributed in the North Chinese platform to Quingbaikou System. The discovery site is situated in the Huainan District of the Anhui Province, where, in 1977, representatives of the biota,

Plate II. Microfossils from the Upper Precambrian *Parmia*-bearing deposits of Timan, Dzhezhim Parma site, Borehole 80, depth interval of 70.0–69.2 m. All pictured specimens are stored at the Geological Institute, Russian Academy of Sciences, Moscow. Scale bars are as follows: 400 μm for fig. 1; 460 μm for figs. 2 and 12; 120 μm for fig. 3; 360 μm for fig. 4; 150 μm for figs. 5, 13, and 15; 60 μm for fig. 6; 90 μm for figs. 7 and 10; 680 μm for figs. 8 and 14; 260 μm for fig. 9; 720 μm for fig. 11.

(1, 8) *Leiotrichoides gracilis* Pjat.: (1) specimen no. 800-901; (8) specimen no. 123-602, aggregate of homogeneous sheaths.

(2) Large filamentous remains displaying oscillatorian structure and consisting of short discoid cells (segments), specimen no. 123-701.

(3) *Glomovertella glomerata* (Jank.), long glomerulate envelopes, specimen no. 123-110.

(4, 9) Wide thin-walled taeniate forms (envelopes ?) with closed rounded endings: (4) specimen no. 800-898; (9) specimen no. 800-400.

(5, 10) *Stiganema*-like branching filaments consisting of envelopes and multiserial cell aggregates: specimen no. 123-611; (10) magnified fragment.

(6) Fine filaments displaying *Lyngbya*-like structure and dark inner zone, presumably the decomposed trichome, specimen no. 123-105.

(7) *Eomycetopsis robusta* Schopf, emend. Knoll, Golubic, mat-like interweaving of narrow sheaths: specimen no. 800-212.

(11) *Segmentothallus asperus* Herm., a fragment of large thallus consisting of short subrectangular segments, specimen no. 123-502.

(12) *Germinosphaera* sp., small drop-like envelope with a long process, specimen no. 123-912.

(13) *Elatera binata* Herm., remains of tubular organisms with fine transverse (spring-shaped) structure, specimen no. 123-599.

(14) *Parmia anastassiae* Gnilovskaya, an integument fragment, specimen no. 123-510.

(15) *Majaphyton antiquam* Tim. et Herm., trilobate thallus, specimen no. 800-897.

the ancient worm-like remains included, were also detected in younger strata of the Jiuliqiao Formation (the Feishui Group of the Sinian "System").[4] In the first publication, Zheng (1980), who originally termed macrofossils as "palaeowermes," described and presented nine photographs of the new genus *Sinosabellidites* Zheng, and also one picture of fossil that was classed with *?Sabellidites* sp. (Plate II, fig. 30 in Zheng, 1980) without any description. The mentioned figure appears to be the first image of Protoarenicolidae form in terms of Hofmann (1994). The same picture and determination result were presented again, and also without description, in two later works (Yang *et al.*, 1980; Chen and Zheng, 1986). In their work of 1986, Sun and his colleagues considered *? Sabellidites* sp., on the basis of its original photograph, as the younger synonym of *Protoarenicola baiguashanensis* Wang, 1982 (Sun *et al.*, 1986). Later, Steiner (1994), who revised the content of the genus *Pararenicola* and used the third publication of the *? Sinosabellidites* picture, interpreted the taxon in question as the younger synonym of *Pararenicola huaiyuanensis* Wang, 1982, representing another genus of Protoarenicolidae.

In the second important publication devoted to the Huainan biota, Wang (1982) monographically described, among other representatives of the biota, the new monotypic genera *Pararenicola* Wang with the species *P. huaiyuanensis* and *Protoarenicola* Wang with the species *P. baiguashanensis* attributing them to the family Arenicolidae of annelids. He described a body that has two preserved endings, with a proboscis at the anterior one, and shows the distinct and uniform annulated structure. The description was supplemented with six pictures, five of which were reproduced in later works (Wang *et al.*, 1984; Sun *et al.*, 1986). It should be emphasized that one repeatedly published figure (Wang, 1982, Plate I, fig. 4; Wang *et al.*, 1984, Plate I, fig. 7; Sun *et al.*, 1986, Plate VII, fig. 11) shows the naturally preserved round section of the tubular organism having thin walls. We suspect that this structure in the internal cavity of the body represents the alimentary canal. In the work of 1982, there were also described several other important taxa: new monotypic genus *Palaeorhynchus* Wang and new species of the genus *Ruedemannella* Howell (*R. minuta*) very similar to *Pararenicola*; new Pogonophora species of the genus *Paleolina* Sokolov; *Sabellidites* sp.; and new monotypic genus *Huainanella.* Pictures of all these fossils, except that of *Sabellidites* sp., were reproduced afterward in 1984 and 1986.

In their paper devoted to stratigraphy, Wang *et al.*, (1984) presented the paleontological plate with images of genera *Pararenicola* (four figs.) and *Protoarenicola* (one fig.) retaining the original nomenclature. In addition, they pictured specimens of genera *Ruedemannella* Howell, *Palaeorhynchus* Wang, and *Paleolina* Sokolov, which are similar, in our opinion, to *Pararenicola* and *Protoarenicola* specimens. In the same year, there was published work devoted to the Huainan biota from Upper Precambrian deposits of the southern Liaodong Peninsula located in another region of northern China. Metazoa remains were found here in the Changlingzi Formation considered by Sun as an analogue of the Jiuliqiao Formation of the Anhui Province (Lin and Xing, 1984). The remains were pictured in two tables and classed with representatives of genera *Sabellidites* Yanichevsky and *Paleolina* Sokolov. In opinion of Sun that we share, the remains belong to the genus *Pararenicola* Wang.

In a monograph devoted to the Late Precambrian paleontology of China, species of genera *Sabellidites* Yanichevsky, *Paleolina* Sokolov, and *Calyptrina* Sokolov are described, in addition to other fossils, together with new genera *Anhuiella* Jan et Xing, 1984 (type species *A. sinensis*) and *Huaiyanella* Xing, Yan et Jin that includes five species (Xing *et al.*, 1985). As we can judge from 36 reproduced photographs, all these organisms are very similar to *Pararenicola* and *Protoarenicola*. In the photograph of *A. sinensis* Yan et Xing (Plate XXXIX, fig. 5), one can clearly see a round cross section of this tubular organism preserved in the natural state. Photographs of *Sabellidites* and *Paleolina* mostly correspond to those illustrating species of the Liaodong locality in the work of 1984.

Chen and Zheng (1986) published their work on the Huainan biota supplemented with two plates. One picture of *Sinosabellidites* specimen was reproduced in this work from the publication of 1980. This specimen can be considered as representing the holotype *S. huainanensis* Zheng(Plate II, figs. 1a and 1b), whereas pictured *Anhuiella, Paleolina*, and *Huaiyanella* specimens (*A. sinensis* Jan et Xing, *P. tortuosa* Wang, *H. striata* Xing et Yan) are, in our opinion, almost identical, together with *Sabellidites* sp., to species of monotypic genera *Pararenicola* and *Protoarenicola*. All the pictures can be found as well in other publications mentioned above.

The first publication in English that was devoted to the Huainan biota is that of Sun *et al.*, (1986). This work accomplished at the University of Adelaide (Australia) presents the investigation results of fossils newly found by Sun and reinvestigation of formerly collected specimens from the Liulaobei and Jiuliqiao formations. The results were discussed in detail with such an expert as Glaessner, and the work was followed by careful comments of Cloud (1986). This publication attracted the worldwide attention and triggered a keen discussion, where Glaessner (1987) demonstrated the necessary spirit of unselfish looking for the scientific truth.

Analyzing the Huainan biota, the cited authors presented monographic description of genera *Sinosabellidites* Zheng, 1980, *Pararenicola* Wang, 1982, and *Protoarenicola* Wang, 1982 in the classical style and

[4] The Rb–Sr age of whole-rock shale samples from the Liulaobei Formation is 840 ± 72 Ma, and the K–Ar age of glauconite from the Jiuliqiao Formation is 738 Ma.

illustrated their specimens (22 photographs). They defined *Huainanella* Wang, 1982 as the younger synonym of the genus *Sinosabellidites*, pointing out that specimen no. A63030 pictured by Zheng in 1980 (Plate II, figs. 20a and 20b) represents the holotype of *S. huainanensis* Zheng. In addition, three species described by Wang in his work of 1982 as *Ruedemannella minuta* Wang, 1982, *Palaeorhynchus anhuiensis* Wang, 1982, and *Paleolina tortuosa* Wang, 1982 were considered as synonyms of *Pararenicola huaiyanensis* Wang, 1982. Thus, Sun and his colleagues disavowed the formerly accepted validity of these three taxa (Wang *et al.*, 1984) and the opinion that *Paleolina tortuosa* represents an independent taxon (Chen and Zheng, 1986). As we believe, this was a correct decision, because all morphological peculiarities of the species are within limits of individual variability and preservation degree of the species *Pararenicola huaiyanensis*. Moreover, these scientists established the holotype of this species (specimen no. A7903 stored at the Institute of Geological Science, the Geological Survey of China, Hefei) that was pictured in their Plate IV (fig. 4) as a reproduction from the earlier work of Wang. They also regarded *?Sabellidites* sp. as a synonym of *Protoarenicola baiguashanensis* representing the monotypic genus *Protoarenicola* Wang. As is already mentioned above, the former was pictured without description in the first work by Zheng (1980, Plate II, fig. 30) and reproduced in several other works (Yang *et al.*, 1980, Plate XVII, fig. 30; Chen and Zheng, 1986, Plate II, fig. 10). The cited scientists selected as well the holotype of *Protoarenicola baiguashanensis* Wang, namely the specimen no. A7906, which is stored at the aforementioned institute and pictured by Sun *et al.* (1986) in their Plate IV (fig. 7).

Judging from description and photographs presented by Sun and his colleagues, genera *Pararenicola* and *Protoarenicola* are similar in general and differ one from another by the shape of proboscis-like structures at the anterior endings of the bodies, and also by the longer and narrower body form of *Protoarenicola* species displaying the more frequent annulated structure. For instance, *Pararenicola* specimens are wider than 1 mm (from 1.2 to 1.8 mm) and not longer than 9.5 mm having 8 to 16 annuli per 1 mm of the body length (10–12 annuli in the holotype). In contrast, *Protoarenicola* specimens are less than 1 mm wide, up to 30 mm long, and have 12 or more annuli per 1 mm of their length. Annuli are distinct and regular in elongated, worm-like bodies representing both taxa. The bodies are carbonaceous and compressed to the filmy state at the bedding planes. Occasionally, the inner body cavity was filled with sedimentary material before the burial, and the natural round cross section of the body was preserved in this case. In the cavity, there were also observed the dark round structures presumably corresponding to the alimentary canal (Sun *et al.*, 1986, Plate VII, figs. 11 and 12). In opinion of the cited authors, the general shape of the body, its definite annulated structure, and terminal elements provide grounds to consider *Pararenicola* and *Protoarenicola* "as worm-like animals of uncertain affinity." It is very important that Cloud (1986) took the work by Sun and colleagues for the "most persuasive ... evidence yet known to me for pre-Ediacarian Metazoa," though he listed as well some doubtful points, for instance the enigma of the Huainan fossils attributed to the genus *Sinosabellidites* Zheng, 1980. In their annulated structure (8–10 annuli per 1 mm of the body length), this genus is very similar to genera *Pararenicola* and *Protoarenicola*, but in the general shape and size ranges of bodies having rounded terminations, it strikingly resembles the genus *Tawuia* Hofmann, 1979, that is usually considered as representing particular algae.

In his comments to the work by Sun *et al.*, Glaessner (1987) wrote that tubular macrofossils of the Huainan biota are so extraordinary that they should be studied very carefully and without prejudice in order to exclude mistakable analogies appearing at the first glance. For instance, his own idea after the quick look at photographs sent to him by Zheng, the author of the genus *Sinosabellidites*, was that the pictured fossils are very similar to the genus *Sabellidites* Yanichevsky, 1926, from Lower Cambrian deposits of the Russian platform. However later, when he studied the materials more attentively, Glaessner admitted that the accomplished work by Sun *et al.* "convinced me that my first opinion was a mistake." We should mention here that there is one principal distinction between two above genera: the genus *Sabellidites* comprises tubular forms open at both ends, whereas tubular bodies from the Huainan biota were occasionally found closed at their ends and having terminal structural elements. Unfortunately, when Vidal and Moczydlowska (1997) dis-

Plate III. Annelodomorphs from *Parmia*-bearing deposits (specimen numbers from collection of the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences). Figures 1–8.

Parmia anastassiae Gnilovskaya, 1998; Upper Riphean, *Parmia*-bearing unit, Russia, southern Timan, Dzhezhim Parma site, Borehole 80: (1) holotype, specimen no. 70-2a-b, completely preserved species with both endings, depth level of 70 m; (2) longest species, specimen no. 55-1a-a,b,c,d, depth level of 46 m; (3) ending of species with visible orbicular cross section, specimen no. 46-1a-h; (4) paratype, specimen no. 70-2b-a; (5) impression and anti-impression of paratype with homonomous body segmentation, specimen no. 70-2a-a, depth level of 70 m; (7) grooves between segments of deformed species, specimen no. 52-2b, depth level of 52 m; (8) grooves between segments and cuticle preserved on the compressed body, specimen no. 70-4-a.

Protoarenicola baiguashanensis Wang, 1982; Upper Riphean, Jiuliqiao Formation; China, Anhui Province, Huainan District: (6) body in a state of peristalsis, image from Chen, 1988, Plate IV, figs. 16 and 17.

Magnifications: ×10 for figs. 1, 3–5, 7, and 8; ×2 for fig. 2; ×20 for fig. 6.

1
2
3
4
5
6
7
8

cussed the Huainan biota, they insisted on the first impression that "organic tubular fossils from the Liulaobei and Jiuliqiao, as we can judge from the illustrations, are extremely similar to *Sabellidites cambriensis*," and they remained to be sure that this impression is a sufficient ground for the further criticism of the work by Sun and his colleagues. Returning to the comments of Glaessner, who saw principal distinctions between genera *Sabellidites* Yanichevsky, 1926, and *Sinosabellidites* Zheng, 1980, we must also remind his words: "Sun convinced me and, to some extent, Cloud that the term *Sinosabellidites* is incorrect in sense, but technically valid," and this viewpoint was accepted later by Hofmann (1994). Considering finally "morphological evidences in favor of obvious metazoan affinity" of representatives of the *Pararenicola* Wang, 1982 and *Protoarenicola* Wang, 1982, Glaessner concluded that additional investigations in the field and laboratory are necessary to clarify the issue. We should notice here that this affinity has got a new support, when the genus *Maotianshania* Sun et Hou, 1987, was distinguished among fossils from the Lower Cambrian deposits of the Yunnan Province in China (Sun and Hou, 1987). *Maotianshania* forms surely belong to the worm group Priapulida widespread beginning from the Middle Cambrian (Burgess Shale of Canada). These organisms had annulated bodies (3–4 annuli per 1 mm of the body length), the alimentary canal, and characteristic proboscis-like structural elements at their anterior ends. In opinion of Sun, the annulated structure and similar organs at the anterior ends of *Protoarenicola* and *Pararenicola* forms suggest that they could be ancient representatives of priapulids, but this suggestion must be verified.

The next publication in English (Chen, 1988) was aimed to discuss the ecology and taphonomy of "Precambrian Metazoa." Chen excluded from consideration the genus *Sinosabellidites* because of its doubtful affinity with Metazoa. He emphasized that representatives of this genus and *Tawuia* Hofmann are similar in their size ranges and morphological features, as the former was obviously devoid of the muscle system necessary for peristaltic movements. Chen analyzed his own collection of *Pararenicola* and *Protoarenicola* remains (about 300 specimens) from the Jiuliqiao Formation, the section of which was thicker than that studied by Sun and his colleagues. According to the isotopic date (K–Ar method) cited by Chen, the formation is as old as 738 Ma. Yin and Sun (1993) reported that the Rb–Sr date for shales of the formation is 754 Ma, and Hofmann (1994) estimated the unit age as corresponding to 770 Ma.

Before the systematic description of fossils, Chen considered in detail their habitat and burial environments. According to him, the Late Proterozoic basin of the region represented a part of shallow sea extending along the southern margin of the Sino-Korean craton between paleolatitudes 20° and 30°. Basal sediments of the Jiuliqiao Formation accumulated in the intertidal zone, whereas the upper part of the formation consists of rhythmically alternating beds of lagoonal micritic limestone and marl, which are extremely rich in fossils. In opinion of Chen, the shallow quiet-water settings and photosynthesis of cyanobacteria could be locally favorable enough for maintenance of animal life. Further, he concludes that *Pararenicola* and *Protoarenicola* are metazoan taxa without doubts and represent the worm-like animals, whose abundant remains are confined to 5–6 successive thin interlayers. The results of field observations exclude, in his opinion, the possibility that organisms were buried during episodes of quick sedimentation. The recurrent mass accumulations of animals are considered as marking the extinction events in response to the episodic oxygen deficiency or changes in salinity of seawater. The character of burials clearly shows that the worm-like animals died suddenly, because some specimens are stranded, other bodies are buried in the state of muscle contraction (Plate III, fig. 6), and particular remains have elongated proboscis-like organs at the anterior ends, which are also indicative of the animal death at the moment of life activity. Analyzing his field observations, Chen determined that the organisms in question were endobionts burying themselves a little in the soft sediment. They consumed the fine detritus and bacteria filtering water through the burrow that had two openings. Populations of these endobiont worms were relatively small, occupying, according to field observations, the areas of few dozens to hundreds of square meters. The population density was controlled by neighboring stromatolitic buildups, where cyanobacteria produced oxygen. In general, the organism affinity with the fossorial benthos may be indicative of the lowest trophic level, where nutrients consisted of alive and dead, partially decomposed plankton. This strategy to sustain life, when the energy consumption is minimal, was, in opinion of Chen, typical of all earliest Metazoa. Finally, Chen discussed the presumable history of Metazoa origin and available evidences in favor of existence of their pre-Ediacarian representatives. According to Chen, the leading factors that influenced the early evolution of Metazoa were glaciations responsible for changes in the water temperature, epicontinental sea areas, and abundance of photosynthesizing biomass. As is established for the Late Riphean–Late Vendian time in China, there were three glaciation epochs separated by periods, when conditions were favorable for the Metazoa development. Accordingly, the period between the Gucheng (second) and Nantou (third) glaciations, but definitely prior to the Luochuan glaciation, was a time of the interglacial transgression that created in shallow zones the ecological niches, where photosynthesis was active and the Huainan biota could develop. The relatively intense ultraviolet radiation presumably forced the early organisms to lead a fossorial life that is evident from the shape of their elongated annulated bodies with dissimilar anterior and posterior ends, from the ability of organisms to perform peristal-

tic motions, and from abundant burrows preserved in sediments. In the paper section devoted to the systematic description, Chen presents, as he states, the modified diagnosis of the species *Pararenicola huaiyuanensis* Wang, 1982, representing the monotypic genus *Pararenicola*. In our opinion, nothing new was presented to better understand the organism structure. Moreover, it seems to be a special case, as compared to the diagnosis given by Sun and his colleagues, and the described characteristics reflect a moment of peristaltic body contraction. We also disagree with Chen that the selected holotype represents the whole organism, sharing the opinion of Sun *et al.* that this specimen is a body fragment. In general, none of photographs published by Chen and Sun *et al.* characterizes the intact organisms with both ends preserved, except for those, where pictured specimens are in the state of peristaltic contraction. Unfortunately, Chen published only four photographs of the species, which are similar one to another and illustrate his understanding of the species volume that is incorrect in our opinion. Following Sun *et al.*, Chen considers *Ruedemannella minuta* Wang and two *Huaiyuanella* species as synonyms of *Pararenicola huaiyuanensis* Wang, and this is the rightful viewpoint. However, two other synonyms listed by Sun *et al.* (*Palaeorhynchus anhuiensis* Wang and *Paleolina tortuosa* Wang), are discarded by Chen in accordance with his understanding of the species limits.

Chen listed *?Sabellidites* sp. Zheng, 1980, and species *Palaeorhynchus anhuiensis* Wang, *Paleolina tortuosa* Wang, and *Anhuiella sinensis* Yang et Xing, the latter very similar to *P. tortuosa*, as synonyms of *Protoarenicola baiguashanensis* Wang representing the second monotypic genus of worm-like organisms.

According to Chen, his diagnosis of *Protoarenicola baiguashanensis* is modified, but in our opinion, it is identical to that given by Sun and his colleagues. The described proboscis-like structure is clearly visible in the published twenty pictures also illustrating peristaltic motions of *Protoarenicola* bodies, their volumetric shape, presumable cross sections of the alimentary canal (Plate I, fig. 6), and burrows created by animals, as Chen suggests. The genus *Protoarenicola* dominant in the Chen's collection characterizes organisms that had very narrow and long bodies (the width to length ratio is 1 : 20 even in fragments) displaying the distinct annulated structure (up to 200 annuli in some specimens). The body form suggests the ability of organisms to move actively over the surface and inside the ground. In opinion of Chen (1988), genera *Pararenicola* and *Protoarenicola* clearly show distinctive features and are independent taxa. We should emphasize, however, that the content of both genera is revised by Chen and differs from that described by Wang and Sun *et al.* For instance, the latter is reduced in volume to the special case characterizing specimens of the former, which were buried in the state of peristaltic contraction and rest.

The last synopsis concerning the Huainan biota was published in German by Steiner (1994) in his monograph devoted to the Neoproterozoic algae from southern China. Analyzing materials of Chinese scientists, he investigated in addition his own collection of carbonaceous macrofossils from the same sections of the Liulaobei and Jiuliqiao formations exposed at the Huai He River. Studying representatives of *Sinosabellidites* Zheng, 1980, and *Pararenicola* Wang, 1982, Steiner revised the former understanding of these organisms and modified their diagnoses. He considers the genus *Sinosabellidites* as a younger synonym of *Tawuia* Hofmann, 1979, pointing out that both organisms are close in shape, have similar size ranges, and occur in association. However, Steiner failed to take into account that the most characteristic feature of *Sinosabellidites* forms is their distinct annulated structure well illustrated by all Chinese paleontologists, the author of the genus included. In contrast, *Tawuia* specimens have uniformly smooth surface, as it is clearly seen in their 19 photographs published by Steiner. In our opinion, the annulated structure is so important feature that *Sinosabellidites* forms displaying it cannot be included in the genus *Tawuia*, though the nature of the former still remains enigmatic. It is necessary to add as well that Hofmann (1994), the author of the genus *Tawuia*, considers *Sinosabellidites* as an independent taxon.

Steiner listed a wide series of synonyms for *Pararenicola* Wang. First of all, these are the second genus of Protoarenicolidae (*Protoarenicola* Wang) and six other genera: a part of *Ruedemannella* Howell (in this case he follow Sun and Chen); *Palaeorhynchus* Wang and a part of *Paleolina* Sokolov (this was formerly done by Sun); *Huaiyuanella* Xing et Jan (Steiner follows Chen here); *Anhuiella* Jan et Xing (this genus was considered by Chen as a younger synonym of *Protoarenicola*); and *?Sabellidites* Zheng, 1980, whose representatives were pictured without description in the first work devoted to the Huainan biota. Unfortunately, Steiner did not present arguments in favor of his idea to include *Protoarenicola* in the genus *Pararenicola*, although Sun and Chen rightfully considered these two taxa as independent genera. Hofmann did the same in his work of 1994 and regarded both genera as members of Protoarenicolidae, thus deriving the family name from the firs genus.

According to the revized Steiner's diagnosis of the genus *Pararenicola*, he considers corresponding organisms as algae *sensu lato* describing their annulated structure as characterizing "transverse bulges arranged more or less regularly." In his interpretation, the proboscis-like structure at one of the organism ends presumably represents an organ of attachment. Unfortunately, this important morphological feature is missing from four photographs and five drawings published by Steiner, although the specific detail like this would be an important evidence in favor of the idea that *Pararenicola* belongs to benthic algae. As we suspect with reservations, Steiner himself might doubt the full-

fledged status and his interpretation of this morphological element. According to him, the "transverse bulges" resemble wrinkles or plicae appearing in some algal thalluses by ageing, but we share the more general opinion that they are elements of the annulated structure, but not wrinkles. As we believe, occasional irregularities in arrangement of these "bulges" can be explained by the irregular preservation of these elements, as it is visible in one of photographs published by Steiner (Plate II, fig. 11). In general, the regular arrangement of the elements (annuli, in our opinion) represents one of distinctive and important features of organisms under consideration. We support the viewpoint of Hofmann (1994) that algae with the regular annulated structure are unknown, and also the statement of Sun that round cross sections of original organisms with these structural patterns prove the animal, but not plant affinity of *Pararenicola* and similar fossils. According to our own investigations, the nonmineralized algae, for instance, the genus *Vendotaenia* Gnilovskaya, 1971, have never been found with round cross sections in the fossil state. Accordingly, we cannot disagree with Glaessner (1986), who pointed out that distinctive features of algae can hardly be recognized in genera *Pararenicola* and *Protoarenicola.* From the our standpoint, Chen (1988), who analyzed the taphonomy and paleoecology of these organisms, presented very convincing arguments in favor of their belonging to the kingdom of animals.

Comparative Analysis

As one can see, all three genera under consideration: *Parmia* Gnilovskaya, 1998, from the Timan biota of Russia, *Pararenicola* Wang, 1982, and *Protoarenicola* Wang, 1982, from the Huainan biota of China, resemble one another. They all represent worm-like organisms that had the annulated body with cross section round in natural state and the closed anterior and posterior ends. The fossils studied characterize mummified organisms, but not their impressions or habitable tubular structures. The homonomous metamerization of the body is the obvious and most characteristic feature of these organisms. All three genera are fairly similar in this aspect: seven metameres in average (the variability range from 2 to 11 depending on the state of peristalsis) characterize 1 mm of the body length of the *Parmia* specimens, and these parameters for *Pararenicola* and *Protoarenicola* forms are 10 (from 8 to 16) and 12, respectively. The average metamere length along the body, as it was estimated with the maximum precision, is 0.14 mm for *Parmia*, 0.10 mm for *Pararenicola*, and 0.08 mm for *Protoarenicola* genera. Thus the annuli frequency in *Parmia* bodies is lesser than that characterizing Chinese genera. The *Parmia* remains also lack proboscis-like structures at their anterior ends, and this is one of important distinctive features that is established for sure, because the structure is absent in that specimen of our collection, which characterizes the fully preserved organism, whereas Chinese scientists described and pictured several times the proboscis-like morphological element (Wang, 1982, Plate I, fig. 3; Plate II, fig. 3; Chen, 1988, Plate III, figs. 10 and 14). Another distinctive feature of *Parmia* remains is the presence of longitudinal cords extending along sides of their bodies. The cords may be elements of the longitudinal muscle system than enforced peristalsis together with the annulated muscles of metameres. In addition, *Parmia* remains had cuticle suitable for plication and more elastic than that of the Chinese genera. All these distinctive features allow us to consider *Parmia* Gnilovskaya as an independent genus of the family Protoarenicolidae Hofmann, 1994. As is mentioned above, it would be correct to include in this family only three listed genera, whereas other taxa (*Huaiyuanella* Xing, Yan et Yin, 1984; *Anhuiella* Yan et Xing, 1984; *Palaeorhynchus* Wang, and, partially, *Ruedemannella* Howell), which were also included by Hofmann in the same family, should be considered as younger synonyms of the former.

CONCLUSION

The results of our study clearly show that macrofossils from Timan, which were attributed to the genus *Parmia* Gnilovskaya, 1998, belong to Metazoa and represent the presumable ancestors of annelids (Gnilovskaya, 1998). In the taxonomic aspect, *Parmia* remains are similar to Protoarenicolidae from the Huainan biota of China (Jiuliqiao and Changlingzi formations) and must be included in this family.

In the studied samples, *Parmia* remains coexist with the representative organic-walled Timan microbiota. This microbiota includes a series of characteristic organic-walled microfossils typical of the Late Riphean: *Chuaria, Trachyhystrichosphaera, Prolatoforma, Segmentothallus, Elatera, Eosolena, Trachytrichoides,* and some others. They all, except for *Chuaria*, are usually untypical of the Vendian. In the Riphean key sections of Siberia and southern Urals, microfossil assemblages of this kind show their first occurrence at the Lakhanda (Bederysh) and correlative levels, whereas assemblages from higher horizons include in addition some complex morphotypes missing from the Timan microbiota. Accordingly, we assume the Early Karatavian age (early Late Riphean) of the *Parmia*-bearing unit. It is important that the mentioned microfossils from the Timan are characteristic of the representative medium-deep ("optimal") grouping of microorganisms that was distinguished in all sedimentary sections accumulated in the Riphean basins. The habitat areas of the grouping corresponded to the lower subtidal and proximal shelf zones of the basins. Tubular cuticular remains and, presumably, *Parmia* remains appear to be typical of most quiet settings within these zones.

Taking for sure that the *Parmia*-bearing unit belongs to the Upper Riphean, our team disagrees in some details concerning the unit position inside the

Upper Riphean erathem, regional stratigraphic scale of the Timan–Urals region, and Dzhezhim Parma section.

In opinion of Bekker, the *Parmia*-bearing unit is an age analogue of the Uk Formation in the Upper Riphean stratotype and should be included in the Tam'yan (Kudash) Horizon, the uppermost one in the Upper Riphean. The opinion is based on his conclusion that the unit position is above that of the Vapol (Pav'yuga) Formation that encloses the Min'yar stromatolites and a marker horizon of cherty dolomite, where microfossils are similar to those known from the Min'yar Formation of southern Urals. Accordingly, Bekker believes that the *Parmia*-bearing unit is post-Min'yar in age and correlative with the Uk Formation overlying the Min'yar Horizon with cherts in the Upper Riphean stratotype.

Olovyanishnikov is of another opinion and suggests that the unit in question is at the Min'yar (Tangaury) level, being a stratigraphic and structural equivalent of the Paun Formation of central Timan, whose rocks overlie and partially replace dolomites of the Pav'yuga Formation. Despite some differences, it is suggested in both viewpoints that the host rocks of *Parmia* remains should be placed at the high levels of the Upper Riphean.

Other authors of the paper are sure that the *Parmia*-bearing unit is older and corresponds not to the upper, but to the lower half of the Upper Riphean, namely to the Bederysh Horizon of the stratotype. Principal in this interpretation are paleontological data on organic-walled microfossils coexisting with annelidomorphs of the Timan. These data undoubtedly suggest the Upper Riphean level of the Timan microbiota and clearly show similarity of the latter with the Bederysh microbiota characterizing the synonymous subformation of the Zil'merdak Formation, the basal unit of the Upper Riphean (Karatavian) stratotype in the southern Urals.

Analyzing all viewpoints, it is necessary to take into account that Bekker and Olovyanishnikov, when they argue for the higher position of the *Parmia*-bearing unit and place it at the level of uppermost Karatavian horizons, consider the northeastern limb of the Dzhezhim Parma structure as a homocline. In this case, the *Parmia*-bearing unit must be, in the stratigraphic succession, above the Pav'yug Formation correlative with the Min'yar levels. Available geological data admit this interpretation, but it is not the only possible, because of the tectonic boundary separating the Pav'yug Formation from the unit under consideration. This fact could be ignored, if macrofossils from the unit would correspond to the Vendian Metazoa, as it was assumed initially. In fact, the situation turned out to be quite different, when we established that these remains are similar to the pre-Ediacarian macrofossils from China and coexist with the Early Karatavian organic-walled microbiota. Judging from all paleontological data obtained, we must assume that the tectonic boundary in the northeast of the Dzhezhim Parma separates the Pav'yug Formation not from the Vendian, but from an older lithostratigraphic unit bearing *Parmia* remains. This assumption is quite probable, because the tectonic boundaries in the Precambrian structure of the Dzhezhim Parma represent the rule rather than exceptions (see Fig. 3). One has to take into account as well that the *Parmia*-bearing deposits are rich in glauconite unlike other Upper Precambrian sediments of the Timan region almost lacking this mineral. In the Dzhezhim Parma area, for instance, glauconite sporadically occurs only in the Vizinga Formation. Thus, the *Parmia*-bearing unit appears to be untypical of the general Upper Riphean succession in the Timan and may represent another facies zone of this level.

The unit under consideration is closer to particular stratigraphic subdivisions of the Polyudov Ridge in the western slope of the Urals, the structure located not far away from the Dzhezhim Parma area. The lower Upper Riphean (Lower Karatavian) includes here the Rassol'nyi Formation generally considered as an analogue of the Zil'merdak Formation in the Riphean stratotype of southern Urals. The upper siltstone and silty shales of the Rassol'nyi Formation are similarly rich in glauconite, and, accordingly, the *Parmia*-bearing unit resembles this formation of the Ural better than the Karatavian lithostratigraphic subdivisions of the Timan Ridge. It is not inconceivable that this unit accumulated in that part of the Karatavian basin, which was situated closer to the Urals than an area, where approximately coeval sediments of the Dzhezhim Formation were deposited. Consequently, the present position of the *Parmia*-bearing unit close to the contact with Pav'yuga Formation is a result of tectonic rock displacements from the side of the Urals.

The considered paleontological data emphasize, however, a somewhat different geological aspect. They allow us to suggest quite surely the Early Karatavian age of the *Parmia*-bearing unit that means the annelidomorph appearance not in the terminal, but in the initial Late Riphean time. It is a forthcoming objective to explain a high organization level of protoarenicolids, the animal organisms of the archaic pre-Ediacarian time. Their occurrence in the very remote regions of the Timan and eastern China may indicate a possibility that similar fossils can be discovered in other localities and, probably, in older deposits.

ACKNOWLEDGMENTS

We are glad to express our gratitude to V.V. Tereshko and S.I. Kirillin, the geologists from the Vychegda Expedition, who donated *Parmia*-bearing rock samples, and also to B.S. Sokolov, M.A. Semikhatov, G.N. Buzhinskaya, M.B. Burzin, T.N. German, M.A. Fedonkin, N.M. Chumakov, and K.E. Yakobson for their helpful comments to our manuscript. The work was supported by The Russian Foundation for Basic Research, project nos. 96-15-98526 and 98-05-64858.

Reviewer M.A. Semikhatov

REFERENCES

Bekker, Yu.R., Abstracts of Papers, *Vseross. soveshchanie "Stratigrafiya, paleontologiya i perspektivy neftegazonosnosti rifeya i venda vostochnoi chasti Vostochno-Evropeiskoi platformy"* (All-Russia Conf. "Stratigraphy, Paleontology, and Oil and Gas Potential of the Riphean and Vendian Deposits of the Eastern Part of the East European Platform"), Ufa, 1999, pp. 7–8.

Burzin, M.B., Late Vendian Helicoid Filamentous Microfossils, *Paleontol. J.*, (Chicago), 1995, vol. 29, no. 1A, pp. 1–34.

Burzin, M.B., Late Vendian (Neoproterozoic III) Microbial and Algal Communities of the Russian Platform: Models of Facies-Dependent Distribution, Evolution and Reflection of Basin Development, *Riv. Ital. Paleontol. Stratigr.* (Milano),1996, vol. 102, no. 3, pp. 307–316.

Chen, J., Precambrian Metazoans of the Huai River Drainage Area (Anhui, E. China): Their Taphonomic and Ecological Evidence, *Senckenbergiana Lethaea*, 1988, vol. 69, no. 3/4, pp. 189–215.

Chen, M. and Zheng, W., On the Pre-Ediacarian Huainan Biota, *Sci. Geol. Sin.*, 1986, no. 3, pp. 221–231.

Chernaya, I.P., Chernyi, V.G., and Raaben, M.E., Main Problems of the Timan Upper Riphean and Vendian Stratigraphy, in *Stratigrafiya verkhnego proterozoya SSSR (rifei i vend)* (Upper Proterozoic Stratigraphy of the USSR: Riphean and Vendian), Leningrad: Nauka, 1979, pp. 102–104.

Chochiya, N.G., Geology of the Kolva–Vishera Basin, *Tr. Vses. Nauchn.-Issled. Geol.- Razved. Inst., Nov. Ser*, 1955, no. 91.

Cloud, P., Reflections on the Beginnings of Metazoan Evolution, *Precambrian Res.*, 1986, vol. 31, pp. 405–408.

Earth's Earliest Biosphere, Schopf, W., Ed., 1983.

German, T.N., *Organicheskii mir milliard let nazad* (Organic World One Billion Years Ago), Leningrad: Nauka, 1990.

Getsen, V.G., Stratigraphic and Tectonic Position of the Upper Riphean Carbonate Sequence in the Timan and Kanin Peninsulas, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1970, vol. 45, no. 1, pp. 58–70.

Getsen, V.G., Late Proterozoic Tectonics of the Northeastern European Platform, *Tr. Inst. Geol. Komi Nauchn. Tsentra Ural Otd. Akad. Nauk SSSR*, 1988, no. 68, pp. 32–46.

Getsen, V.G. and Dedeev, V.A., Regional Stratigraphic Scheme for the Upper Precambrian of the Northern European Part of the USSR, in *Stratigrafiya verkhnego proterozoya SSSR (rifei i vend)* (Upper Proterozoic Stratigraphy of the USSR: Riphean and Vendian), Ufa: Akad. Nauk SSSR, 1990, pp. 48–49.

Getsen, V.G. and Pykhova, N.G., Riphean Stratigraphy of the Central Timan Area, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1977, no. 6, pp. 69–80.

Glaessner, M., Discussion about Some "Worm-Like" Fossils, *Precambrian Res.*, 1987, no. 36, pp. 353–355.

Gnilovskaya, M.B., Oldest Annelidomorphs of the Upper Riphean from the Timan, *Dokl. Ross. Akad. Nauk*, 1998, vol. 359, no. 3, pp. 369–372.

Golovenok, V.K. and Belova, M.Yu., Microfossils in the Precambrian Biostratigraphy: Methods of Studying and Application, in *Region. Geol. Mineral.* (St. Petersburg), 1995, no. 4, pp. 63–75.

Hofmann, H., Proterozoic Carbonaceous Compressions ("Metaphytes" and "Worms"), *Early Life on Earth. Nobel Symp.*, 1994, no. 84, pp. 343–367.

Hofmann, H.J. and Jackson, G.D., Shale-Facies Microfossils from the Proterozoic Bylot Supergroup, Baffin Island, Canada, *Mem. Paleontol. Soc.*, 1994, vol. 37, no. 4.

Keller, B.M., *Verkhnii proterozoi Russkoi platformy (rifei i vend)* (The Upper Proterozoic of the Russian Platform: Riphean and Vendian), Moscow: Mosk. Gos. Univ., 1968.

Keller, B.M. and Yankauskas, T.V., Microfossils from the Riphean Stratotype in the South Urals, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1980, no. 12, pp. 58–67.

Knoll, A.H., Proterozoic and Early Cambrian Protists: Evidence for Accelerating Evolutionary Tempo, *Proc. Nat. Acad. Sci. USA*, 1994, vol. 91, no. 6, pp. 6743–6750.

Knoll, A.H. and Golubic, S., Anatomy and Taphonomy of a Precambrian Algal Stromatolite, *Precambrian Res.*, 1979, vol. 10, pp. 115–151.

Knoll, A.H. and Sergeev, V.N., Taphonomic and Evolutionary Changes across the Mezoproterozoic–Neoproterozoic Transition, *Neues Jahrb. Geol. Paleontol. Abh.*, 1995, vol. 195, nos. 1–3, pp. 289–302.

Lin, W. and Xing, Y., Results of Studies of Metazoa of the Group Liaonan from the Sinian of the Southern Liaodong Peninsula, in *On the Upper Precambrian in Southern Liaodong Peninsula*, Shenyang: Inst. Geol. Mineral. Res. CAGS, 1984, pp. 51–63.

Mikhailova, N.S., Precambrian Microfossils from the Western and Southern Margins of the Siberian Platform and Their Stratigraphic Significance, *Cand. Sci. (Geol.-Mineral.) Dissertation*, Leningrad: Inst. Precambr. Geol. Geochronol., 1985.

Mikrofossilii dokembriya SSSR (Precambrian Microfossils of the USSR), Leningrad: Nauka, 1988.

Miloradovich, B.V., Geology of the Dzhezhim Parma, Southern Timan, *Tr. Neft. Geol.-Razved. Inst., Ser. A*, 1938, no. 53.

Nalivkin, A.B., Stratigraphy and Tectonics of the Timan Metamorphic Sequences, *Trudy soveshchaniya po utochneniyu unifitsirovannykh stratigraficheskikh skhem paleozoya Volgo-Ural'skoi neftyanoi provintsii* (Proc. Conf. on Unified Paleozoic Stratigraphic Schemes for Volga–Ural Oil-Bearing Province), Moscow: Gostoptekhizdat, 1962, pp. 122–123.

Olovyanishnikov, V.G., *Verkhnii dokembrii Timana i poluostrova Kanin* (The Upper Precambrian of the Timan and the Kanin Peninsula), Yekaterinburg: Komi Nauchn. Tsentr Ural Otd. Ross. Akad. Nauk, 1998.

Petrov, P.Yu. and Veis, A.F., Facial-Ecological Structure of the Derevnya Formation Microbiota: Upper Riphean, Turukhansk Uplift, Siberia, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 5, pp. 13–40.

Plumb, K.A., New Precambrian Time Scale, *Episodes*, 1991, vol. 14, no. 2, pp. 139–140.

Pyatiletov, V.G., Late Precambrian Microfossils from the Uchur–Maiya Basin, in *Pozdnii dokembrii i rannii paleozoi Sibiri. Vend i rifei* (Late Precambrian and Early Paleozoic of Siberia: Vendian and Riphean), Novosibirsk: Inst. Geol. Geofiz., Sib. Otd. Akad. Nauk SSSR, 1988, pp. 47–94.

Raaben, M.E., *Stromatolity verkhnego rifeya (gimnosolenidy)* (Upper Riphean Stromatolites: Gymnosolenids), Moscow: Nauka, 1969.

Raaben, M.E., *Verkhnii rifei kak edinitsa obshchei stratigraficheskoi shkaly* (The Upper Riphean as a Unit of the Standard Stratigraphic Scale), Moscow: Nauka, 1975.

Raaben, M.E., Upper Precambrian Phytoliths in the Northern European Part of the USSR, in *Rifei i vend Evropeiskogo Severa SSSR* (The Riphean and Vendian of the Northern European Part of the USSR), Syktyvkar: Komi Fil. Akad. Nauk SSSR, 1987, pp. 34–40.

Raaben, M.E. and Oparenkova, L.I., New Data on the Riphean Stratigraphy of Timan, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 2, pp. 13–20.

Raaben, M.E. and Zabrodin, V.E., *Vodoroslevaya problematika verkhnego rifeya* (Upper Riphean Algal Problematics), Moscow: Nauka, 1972.

Raznitsyn, V.A., Reversed Faults in the Dzhezhim Parma Area of the Southern Timan, *Dokl. Akad. Nauk SSSR*, 1961, vol. 140, no. 2, pp. 430–433.

Raznitsyn, V.A., *Rifeiskie otlozheniya Timana* (Riphean Deposits of the Timan), Leningrad: Nauchn.-Issled. Inst. Geol. Arctic, 1962, pp. 37–57.

Raznitsynn, V.A., *Tektonika Yuzhnogo Timana* (Tectonics of the Southern Timan), Moscow: Nauka, 1964.

Rifei i vend Evropeiskogo Severa SSSR (The Riphean and Vendian of the Northern European Part of the USSR), Syktyvkar: Komi Fil. Akad. Nauk SSSR, 1987.

Rostovtsev, N.N., Upper Paleozoic–Riphean Succession in the Northwestern Kel'tmen' Rampart, *Sov. Geol.*, 1948, no. 28, pp. 16–31.

Semikhatov, M.A., *General Problems of Proterozoic Stratigraphy in the USSR, Soviet Sci. Rev. Sec. G. Geology*, vol. 1, pt. 1, New York: Harwood Acad., 1991.

Semikhatov, M.A., Methodical Principles of the Riphean Stratigraphy, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 6, pp. 33–50.

Semikhatov, M.A., General Subdivisions of the Precambrian: Comparison of the Latest Scales, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 6–20.

Sokolov, B.S., *Ocherki stanovleniya venda* (Essays on Recognition of the Vendian), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1998.

Solntsev, O.A., Metamorphic Shales, *Tr. Vses. Nauchn.-Issled. Geol.-Razved. Inst.*, 1959, no. 133, pp. 5–18.

Steiner, M., Die neoproterozoischen Megaalgen Sudchinas, *Berlin. Geowiss. Abh. E*, 1994, vol. 15, pp. 1–146.

Steiner, M., *Chuaria circularis* Walcott, 1899,—Megaspheromorphic Acritarchs or Prokaryotic Colony? *Acta Univ. Carolinae. Geol.*, 1996, vol. 40, nos. 3–4, pp. 645–665.

Stratigraficheskii slovar (Severnaya Evraziya v granitsakh byvshego SSSR). Verkhnii dokembrii (Glossary of Stratigraphy: Northern Eurasia within Limits of the Former USSR, the Upper Precambrian), Moscow: Nauka, 1994.

Stratotip rifeya. Stratigrafiya. Geokhronologiya (The Riphean Stratotype. Stratigraphy. Geochronology), Moscow: Nauka, 1983.

Sun, W. and Hou, X., Early Cambrian Worms from Chengjiang, Yunnan, China, *Maotianshania* Gen. Nov., *Acta Palaeontol. Sin.*, 1987, no. 5, pp. 299–305.

Sun, W., Wang, G., and Zhou, B., Macroscopic Worm-Like Body Fossils from the Upper Precambrian (900–700 Ma), Huainan District, Anhui, China and Their Stratigraphic and Evolutionary Significance, *Precambrian Res.*, 1986, vol. 31, pp. 377–403.

Sun, W., Late Precambrian Pennatulids (Sea Pens) from Eastern Yangtze Gorge, China: *Paracharnia* gen. nov., *Precambrian Res.*, 1986, vol. 31, no. 4, pp. 361–375.

Tereshko, V.V. and Kirillin, S.I., New Data on Upper Proterozoic Stratigraphy of the Southern Timan, in *Stratigrafiya verkhnego proterozoya SSSR (rifei i vend)* (Upper Proterozoic Stratigraphy of the USSR: Riphean and Vendian), Ufa: Akad. Nauk SSSR, 1990, pp. 81–82.

The Proterozoic Biosphere, Schopf, J.W. and Klein, C., Eds., 1992.

Veis, A.F., Riphean and Vendian Microfossils from the Uchur–Maiya and Turukhansk Areas of Siberia, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1988, no. 5, pp. 47–64.

Veis, A.F., Precambrian Organic-Walled Microfossils as Significant Components of the Ancient Biota, in *Problemy doantropogennoi evolyutsii biosfery* (Problems of the pre-Anthropogene Biosphere Evolution), Moscow: Nauka, 1993, pp. 265–282.

Veis, A.F. and Larionov, N.N., Abstracts of Papers, *Vseross. soveshchanie "Stratigrafiya, paleontologiya i perspektivy neftegazonosnosti rifeya i venda vostochnoi chasti Vostochno-Evropeiskoi platformy"* (All-Russia Conf. "Stratigraphy, Paleontology, and Oil and Gas Potential of the Riphean and Vendian Deposits of the Eastern Part of the East European Platform"), Ufa, 1999, pp. 17–19.

Veis, A.F. and Petrov, P.Yu., The Main Peculiarities of the Environmental Distribution of Microfossils in the Riphean Basins of Siberia, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 5, pp. 97–129.

Veis, A.F. and Vorob'eva, N.G., Microbiotas of the Kerpyl' Group in the Riphean Hypostratotype of Siberia, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 41–58.

Veis, A.F. and Vorob'eva, N.G., New Data on Composition and Stratigraphic Significance of the Late Riphean Miroedikha Microbiota, (Turukhansk Area, Siberia), *Dokl. Ross. Akad. Nauk*, 1998, vol. 358, no. 6, pp. 794–798.

Veis, A.F., Petrov, P.Yu., and Vorob'eva, N.G., The Late Riphean Miroedikha Microbiota from Siberia. Part 1. Composition and Facial-Ecological Distribution of Organic-Walled Microfossils, *Stratigr. Geol. Korrelyatsiya*, 1998a, no. 5, pp. 15–38.

Veis, A.F., Petrov, P.Yu., and Vorob'eva, N.G., Secular Changes in Facial-Ecological Structure of Ancient Biotas and Riphean Stratigraphy, *Geol. Geofiz.*, 1998b, vol. 39, no. 1, pp. 85–96.

Veis, A.F., Larionov, N.N., Vorob'eva, N.G., and Li, S.-D., Microfossils in the Riphean Stratigraphy of the Southern Urals (Bashkir Meganticlinorium) and cis-Urals Area (Kama–Belaya Avlacogene), *Stratigr. Geol. Korrelyatsiya*, (in press).

Velikanov, V.A., Aseeva, E.A., and Fedonkin, M.A., *Vend Ukrainy* (The Vendian of the Ukraine), Kiev: Naukova Dumka, 1983.

Vendskaya sistema (The Vendian System), Sokolov, B.S., Ivanovskii, A.B., Fedonkin, M.A., Eds., Moscow: Nauka, 1985.

Vidal, G. and Moczydlowska, M., Biodiversity, Speciation, and Extinction Trends of Proterozoic and Cambrian Phytoplankton, *Paleobiol. Soc.*, 1997, vol. 23, no. 2, pp. 230–246.

Vidal, G., Moczydlowska, M., and Rudavskaya, V.A., Biostratigraphical Implications of a Chuaria–Tawuia Assemblage and Associated Acritarchs from the Neoproterozoic of Yakutia, *Palaentology*, 1993, vol. 36, part 2, pp. 387–402.

Vladimirskaya, E.V., Pre-Devonian Deposits of the Kolva–Vishera Area, *Tr. Vses. Nauchn.-Issled. Geol.-Razved. Inst.*, 1955, no. 90, pp. 225–280.

Volkova, N.A., Facies Confinement of Paleozoic Acritarchs, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 2, pp. 71–74.

Volochaev, F.Ya., Kukushkin, A.I., and L'vov, K.A., On Stratigraphy of Oldest Deposits in the Timan, *Dokl. Akad. Nauk SSSR*, 1967, vol. 137, no. 6, pp. 1389–1392.

Wang, G., Late Precambrian Annelida and Pogonophora from the Huainan of Anhui Province, *Bull. Tianjin. Inst. Geol. Mineral. Res.*, 1982, no. 6, pp. 9–22.

Wang, G., Zhou, B., and Xiao, L., Late Precambrian Macrofossils from Huainan, Anhui and Their Significance, *J. Stratigr.*, 1984, pp. 271–278.

Xiao, S., Knoll, A.H., and Kaufman, A.J., Neoproterozoic Fossils in Mezoproterozoic Rocks? Chemostratigraphic Resolution of a Biostratigraphic Conundrum from the North China Platform, *Precambrian Res.*, 1997, vol. 84, pp. 197–220.

Xing, Y., Ding, Q., Lin, W., Yan, Y., and Zhang, L., Metazoans and Trace Fossils, in *Late Precambrian Paleontology of China*, 1985, pp. 182–192.

Yang, Q., Zhang, Y., Zheng, W., and Xu, X., Subdivision and Correlation of Sinian Suberathem in Northern Jiangsu and Anhui, in *Res. Precambrian Geol. Sinian Suberathem in China*, Tianjin, 1980, pp. 231–265.

Yin, L. and Sun, W., Microbiota from the Neoproterozoic Liulaobei Formation in the Huainan Region, Northern Anhui, China, *Precambrian Res.*, 1994, vol. 65, no. 2, pp. 95–114.

Zabrodin, V.E., Catagraphs of the *Vesicularites* Reitl. Group, Their Diagnostic Features and Methods of Studying, in *Problematika pogranichnykh sloev rifeya i kembriya Russkoi platformy* (Problematics of the Riphean–Cambrian Boundary Beds of the Russian Platform), Moscow: Nauka, 1968, pp. 37–83.

Zhang, W. and Walter, M.R., Late Proterozoic and Early Cambrian Microfossils and Biostratigraphy, Northern Anhui and Jiangsu, Central-Eastern China *Precambrian Res.*, 1992, vol. 57, pp. 243–323.

Zheng, W., A New Occurrence of Fossil Group of *Chuaria* from the Sinian System in North Anhui and Its Geological Meaning, *Hefei Polytechn. Univ., Dept. Geol.*, 1980, no. 1, pp. 49–69.

Zhuravlev, V.S. and Osadchuk, M.I., The Timan Ridge and the Kanin Peninsula, in *Verkhnii dokembrii* (The Upper Precambrian), Moscow: Gosnauchtekhizdat, 1963, pp. 206–238.

Zhuravlev, V.S., Zabrodin, V.E., Raaben, M.E., and Chernyi, V.G., On Stratigraphy of the Timan Ridge Basement, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1966, vol. 41, no. 2, pp. 49–75.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 353–361. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 40–48.
Original Russian Text Copyright © 2000 by Konstantinov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Correlated Ammonoid Zonation in Ladinian Deposits of the Boreal Realm

A. G. Konstantinov

Institute of Geology, Siberian Division, Russian Academy of Sciences, pr. Koptyuga 3, Novosibirsk, 630090 Russia

Received May 15, 1998

Abstract—Tsvetkovitids and nathorstitids (Ammonoidea) from the entire Boreal realm are revised on the basis of most recent data on their morphology, systematics, and evolution. The elucidated stratigraphic ranges of both taxonomic groups are used to establish the correlated ammonoid zonation in Ladinian deposits of northeastern Asia, Svalbard, Arctic Canada, Franz Josef Land and British Columbia. Ammonoid faunas from British Columbia consist of mixed Boreal and Tethyan taxa useful for correlation of Ladinian biostratigraphy in Boreal regions with the standard Alpine scale.

Key words: *northeastern Asia, Svalbard, Canada, Franz Josef Land, Southern Alps, biostratigraphy, correlation, Ladinian Stage, ammonoids.*

INTRODUCTION

The Ladinian Stage biozonation that would be generally acceptable has not been authorized so far, and positioning of lower and upper boundaries of the stage is still a subject of long-lasting discussion. In 1993, the International Working Group on the Anisian–Ladinian Boundary made an attempt to solve the problem during the field excursion to classical sections of Anisian–Ladinian boundary beds in Southern Alps of Italy and Balaton Highlands of Hungary (*Anisian/Ladinian...*, 1993). Analyzing stratigraphic ranges of ammonoids and discussing correlation between the sections, the group was however unable to choose the final version among three possible positions: at the base of either *Reitziites reitzi* or *Nevadites* and *Eoprotrachyceras curionii* zones. In my work, I accept the last version, because this level marks a considerable change in the ammonoid fauna—the first occurrence of trachyceratids (Genus *Eoprotrachyceras*). In addition, the version is most convenient for the global correlation. I also place the upper boundary of Ladinian Stage at the base of the *Trachyceras aon* Zone, where this index species appears for the first time. The last of chosen boundary positions agrees well with the priority principle, since the *Trachyceras aon* Zone was originally distinguished in the Dolomite Alps as the basal one in the Carnian Stage (Mojsisovics, 1882).

There are many problems concerning correlation of Ladinian deposits in the Boreal and Tethyan paleobiogeographic regions. One is related to the fact that the Ladinian Age was a time of intense biogeographic differentiation of ammonoids, whose evolution decelerated (Dagys *et al.*, 1979; Shevyrev, 1986). It is impossible to distinguish even short-term phases of that period, when taxonomic composition of ammonoid communities in separate biochores was differentiated, and specific taxa dominated in the Boreal basins throughout the Ladinian Age. On the other hand, Ladinian ammonoids are poorly, or inadequately studied in some particular regions. The nomenclature problems and difficulties in correlation procedure reflect a disappointing state of systematics for certain ammonoid groups. It is necessary therefore to reclassify the respective taxa, given that correlation of Ladinian deposits in northeastern Asia and other regions was so far conditional to a considerable extent, even if the deposits yielded some identical boreal forms (Dagys *et al.*, 1979; Tozer, 1981; Dagys and Tozer, 1989; Weitschat and Dagys, 1989).

The recent progress in comprehensive study of ammonoids was used to elaborate the ammonoid zonation of the Ladinian Stage in Svalbard (Weitschat and Lehman, 1983; Dagys *et al.*, 1993; Dagys and Weitschat, 1993), northeastern Asia (Dagys *et al.*, 1991; Dagys and Konstantinov, 1992, 1995, 1997), and Canada (Tozer, 1994). Revising the formerly known sections of the stage and investigating new sequences bearing ammonoids in the type area of Southern Alps, Mietto and Manfrin (1995) finally suggested the detailed standard scale of the Ladinian Stage.

New data also give a chance to refine correlation of Ladinian deposits in the Boreal realm by means of coordinating zonations of boreal ammonoids with the Alpine scale and by discussing some problems pertaining to the issue.

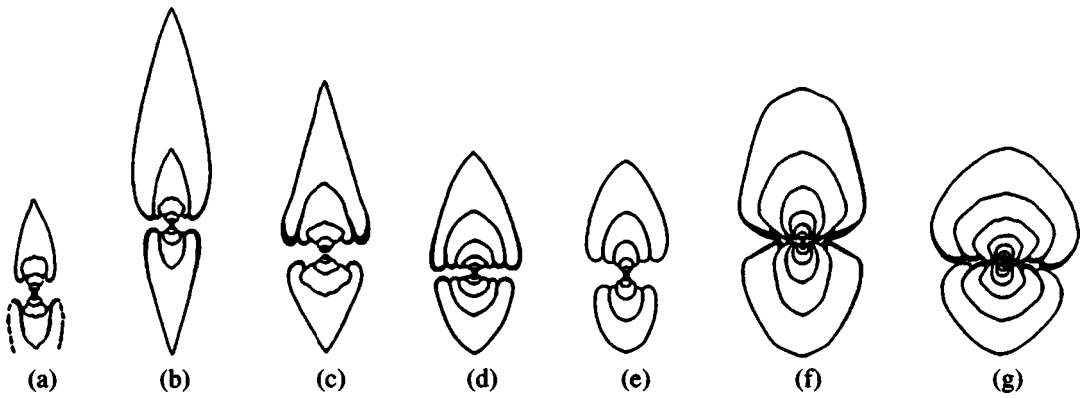


Fig. 1. Transverse sections of tsvetkovitid and nathorstitid shells (×1): (a) *Eonathorstites oleshkoi* (Archipov), specimen no. 286/811*, Laptev Sea, Ulakhan-Crest Cape, *oleshkoi* Zone; (b) *Tsvetkovites constantis* (Archipov), specimen no. 1/994, Kharaulakh Range, Nyakuchan River, *constantis* Zone; (c) *Ts. neraensis* (Popow), specimen no. 39/994, Laptev Sea, Ulakhan-Crest Cape, *neraensis* Zone; (d) *Indigirites krugi* Popow, specimen no. 62/994, Lena River, Taas-Aryy Is., *krugi* Zone; (e) *Nathorstites maclearni* Tozer, specimen no. 71/994, Dzhugadzhak River, *maclearni* Zone; (f) *N. macconnelli* (Whiteaves), specimen no. 79/994, Pravaya Vtoraya Sentyabr'skaya River, *macconnelli* Zone; (g) *N. lindstroemi* Böhm, specimen no. 91/994, Dzhugadzhak River, *lindstroemi* Zone.
*Collections 811 and 994 are stored at the Central Geological Museum of Siberia, Siberian Division, Russian Academy of Sciences, Novosibirsk.

BIOCHRONOLOGICAL BASIS OF CORRELATION

Ladinian deposits in Boreal regions frequently yield ammonoids, but their assemblages, as compared to coeval faunas from low latitudes, are less diverse and usually monotonous in composition. Suffice it to say that number of genera in the Middle Triassic ammonoid assemblages from Boreal regions is three times lesser than in coeval Tethyan faunas (Dagys *et al.*, 1979). Ammonoids representing family Nathorstitidae Spath, 1951, are dominant in Ladinian assemblages from Boreal regions. They are widespread in northeastern Asia (Arkhipov, 1974; Bychkov, 1982; Dagys *et al.*, 1991), Svalbard (Böhm, 1903; Stolley, 1911; Frebold, 1929; Korchinskaya, 1972, 1982), Arctic Canada (Tozer, 1961), and Franz Josef Land (Korchinskaya, 1985). In British Columbia, where Tozer (1967, 1994) elaborated the most detailed ammonoid zonation for the Ladinian Stage, nathorstitids coexist with various Tethyan ammonoids. Accordingly, data on chronological successions of Nathorstitidae genera and species can be used for correlation of Ladinian ammonoid zonations in the Boreal and Tethyan regions, but the stratigraphic potential of this fauna was underused because the group and its systematics have been poorly known before.

Principal trends in morphological evolution of nathorstitids and their phylogeny were elucidated, when the group was recently revised by using the type material from Siberia and comprehensive data on original specimens from Canada and Svalbard (Dagys and Konstantinov, 1997). Several taxa formerly attributed to nathorstitids are now classed with the family Tsvetkovitidae consisting of three successive, exclusively boreal genera, whose early long-evolving oxycone is sculptured, whereas the mature conch usually has thin oxycone and shows lobe line with the pseudoadventive elements. These are genera *Intornites* (Anisian) → *Eonathorstites* (Ladinian, the *oleshkoi* Zone) → *Tsvetkovites* (Ladinian, the *constantis* and *neraensis* zones). The nathorstitids proper are definite descendants of tsvetkovitids. They are represented again by three, chronologically successive boreal genera: *Indigirites* (Ladinian, the *krugi* Zone) → *Nathorstites* (Ladinian, the *maclearni, macconnelli*, and *lindstroemi* zones) → *Stolleyites* (Carnian, the *tenuis* Zone). These taxa had shells of the subspherocone type and simpler lobe lines lacking the pseudoadventive elements.

Eonathorstites is the oldest Ladinian genus of tsvetkovitids. Mature shells of the genus were of a narrow oxycone type and had an acute ventral side (Fig. 1a). Their lobe line consisted of highly dentate lobes and acute phylloid saddles (Fig. 2a). Genus *Tsvetkovites* is descendant of the former and occurs in higher horizons of the sequence. At the mature stage, it retained the whorl morphology characteristic of ancestral conchs, but shells of this genus were of the cadicone type at the intermediate stage of growth (Fig. 1b). During the *krugi* time, last representatives of the genus *Tsvetkovites* (Figs. 1c and 2c) gave rise to first nathorstitids with different morphology of inner whorls as compared to that of the ancestral family (Figs. 1d–1g). When the genus *Indigirites*, subsequently followed by genera *Nathorstites* and *Stolleyites*, appeared in the phyletic line, the morphogenesis of principal shell elements slowed down, and descendants liberated themselves from the final evolutionary stages of ancestral forms. Their lobe line was simplified; it had a lesser number of less dentate lobes combined with less phylloid and more rounded saddles (Fig. 2).

The established morphogenetic succession of tsvetkovitid and nathorstitid taxa was used as the phylogenetic basis for the Ladinian ammonoid zonation in northeastern Asia (Dagys and Konstantinov, 1992, 1995). It is clear now that the successive taxa are tightly interrelated, as they show gradual changes in the shell shape, ornamentation, and lobe line configuration. In addition, progeny retains some archaic features of ancestral taxa, and all this suggests, if we take into account the endemism of ammonoids under consideration, that the elaborated zonation lacks any significant hiatus and adequately reflects all evolutionary stages of the considered fauna.

A similar chronological succession of tsvetkovitid and nathorstitid genera and species is established as well in sedimentary sequences of Svalbard, Arctic Canada, and British Columbia. Some nathorstitid taxa are perfectly studied in the Franz Josef Land. The ammonoids under consideration represent either the index species or zonal guide fossils offering a good chance to correlate in detail the Ladinian deposits in Boreal regions (Table 1). In addition, the ecotone sections of British Columbia, where the ammonoid fauna is of the mixed Boreal–Tethyan type, can be used for coordination of Boreal and Alpine ammonoid zonations (Table 2).

CORRELATIVE LADINIAN SECTIONS IN BOREAL REGIONS

Svalbard Archipelago. In the so-called upper *Daonella* Shales of the Botneheia Formation, Weitschat and Lehmann (1983) recognized three levels of bituminous carbonate nodules. In the lower one situated 10–15 m above the base of the *Daonella* Shales, they detected the late Anisian faunas of ammonoids and bivalves characterizing the *Frechites laqueatus* (Lindström), *Aristoptychites* (=Ptychites) *trochlaeformis* (Mojsisovics), *Ussurites spetsbergensis* (Oberg), and *Daonella lindstroemi* Mojsisovics zones.

The middle level with nodules, ten meters above the first one, yielded ammonoids *Tsvetkovites varius* Weitschat et Lehmann, *Aristoptychites* (=Aristoptychites) *euglyphus* Mojsisovics, and *Ussurites spetsbergensis* (Oberg). The level was termed as the *Tsvetkovites varius* Zone of the lower Ladinian (Weitschat and Lehmann, 1983).

A few meters below the top of the *Daonella* Shales, there is the third level of nodules bearing ammonoids *Aristoptychites kolymensis* (Kiparisova), *Indigirites tozeri* Weitschat et Lehmann, *Ussurites spetsbergensis* (Oberg), and *Proarcestes* forms in association with bivalves *Daonella degeeri* Böhm. These fossils are characteristic of the *Indigirites tozeri* Zone that has been originally attributed to the lower Ladinian (Weitschat and Lehmann, 1983) and displaced later into the basal upper Ladinian (Weitschat and Dagys, 1989).

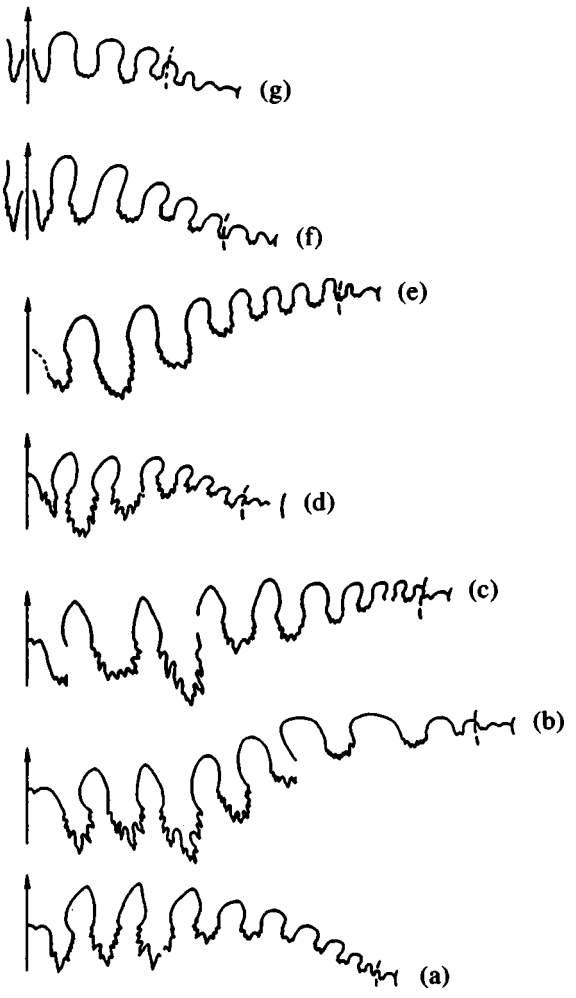


Fig. 2. Lobe lines of tsvetkovitids and nathorstitids: (a) *Eonathorstites oleshkoi* (Archipov), specimen no. 312/811, width (W) = 12 mm, height (H) = 25 mm, Laptev Sea, Ulakhan Crest Cape, *oleshkoi* Zone; (b) *Tsvetkovites constantis* (Archipov), specimen no. 10/994, W = 24 mm, H = 50 mm, Kharaulakh Range, Nyakuchan River, *constantis* Zone; (c) *Ts. neraensis* (Popow), specimen no. 36/994, H = 15 mm, Laptev Sea, Tumul Cape, *neraensis* Zone; (d) *Indigirites krugi* Popow, specimen no. 52/994, W = 17.5 mm, H = 15 mm, Indigirka River, Turakh-Yuryakh Creek, *krugi* Zone; (e) *Nathorstites maclearni* Tozer, specimen no. 77/994, W = 15.8 mm, H = 21.6 mm, Dzhugadzhak River, *maclearni* Zone; (f) *N. macconnelli* (Whiteaves), specimen no. 86/994, W = 16.6 mm, H = 15.5 mm, Dzhugadzhak River, *macconnelli* Zone; (g) *N. lindstroemi* Böhm, specimen no. 97/994, W = 16.7 mm, H = 10.5 mm, Dzhugadzhak River, *lindstroemi* Zone.

The *varius* and *tozeri* zones of Svalbard can be easily correlated with coeval Ladinian zones in northeastern Asia, where shells of *Tsvetkovites varius* are concentrated in the lower part of the *Tsvetkovites constantis* Zone (Dagys and Konstantinov, 1995). The *varius* Zone of Svalbard thus corresponds to a lower part of the *constantis* Zone. The *Indigirites tozeri* and *Indigirites krugi* zones appear to be stratigraphic equivalents,

Table 1. Correlation scheme for Ladinian deposits in the Boreal regions

Substage	Northeastern Asia (Dagys and Konstantinov, 1995)	Arctic Canada (Tozer, 1994)	Svalbard Archipelago		Franz Josef Land (Korchinskaya, 1985)
			Spitsbergen (Weitschat and Lehmann, 1983; Weitschat and Dagys, 1989; with modifications)	Bear Island (Dagys *et al.*, 1993)	
Upper	*Nathorstites lindstroemi*	*Nathorstites* Beds	*Nathorstites* Beds	*Nathorstites lindstroemi*	*Daonella subarctica*
	Nathorstites macconnelli				*Daonella frami*
	Nathorstites maclearni		*Protrachyceras* and *Daonella* ex gr. *subarctica* beds		*Daonella parva* *Daonella* aff. *prima*
	Indigirites krugi	*Daonella frami* Beds	*Indigirites tozeri*		*Indigirites krugi*
	Tsvetkovites neraensis				*Daonella* cf. *arctica*
	Tsvetkovites constantis		*Tsvetkovites varius*		*Meleagrinella* cf. *omolonensis*
Lower	*Eonathorstites oleshkoi*				*Dacryomya scorochodi*

because the common genus and species *Indigirites tozeri* and *Aristoptychites kolymensis* are present in both units.

Taxa characterizing the *Eonathorstites oleshkoi* and *Tsvetkovites neraensis* zone of Siberia are unknown in Svalbard, and presence of respective zonal units in this archipelago seems to be problematic.

It is difficult to establish in Svalbard the stratigraphic equivalents of *Nathorstites maclearni, N. macconnelli*, and *N. lindstroemi* zones of northeastern Asia. The *macconnelli* Zonė is distinguished by Korchinskaya (1982) in her stratigraphic scheme of Ladinian deposits as a consequence of incorrect determinations of nathorstitids (Weitschat and Dagys, 1989). In my opinion, it is possible to class with *Nathorstites macconnelli* (Whiteaves) only those ammonoids, which have constrictions in the early whorls like in the Canadian type species (Tozer, 1994, Plate 86, fig. 3b, Plate 87, fig. 4) and are described as *Nathorstites strongulatus* Korchinskaja (Korchinskaya, 1972, p. 69, Plate 2, figs. 10–12). These ammonoids are recovered from the upper Ladinian phosphorite nodules of the Agarddalen section (Ruslagenfjellet) in the eastern coast of Spitsbergen, where they occur below the level of *Zittelihalobia zitteli* (Lindström) and *Stolleyites* cf. *tenius* (Stolley). At the same time, ammonoids from upper Ladinian deposits in the southeastern coast of this island were also classed with *Nathorstites macconnelli* (Korchinskaya, 1972, p. 68, Plate 2, figs. 8 and 9), although their swollen cadicone shells have the almost straight growth lines and the well-developed umbilical depression bounded by umbilical shoulder. As shown by Dagys and Konstantinov (1997), all these features better correspond to *Nathorstites lindstroemi* (Böhm) that has been also found in the 0.5-m-thick bed of dark gray siltstone bearing abundant phosphorite nodules (Dagys *et al.*, 1993). In the overlying gray siltstone, frequent siderite nodules taking rusty dye by weathering yield ammonoids of genera *Stolleyites, Paracladiscites*, and "*Discophyllites*" (=*Arctophyllites*) in association with nautiloids and bivalves *Zittelihalobia zitteli* Lindstr. Unfortunately, *Nathorstites macconnelli* (Whit.) and *N. lindstroemi* Böhm do not occur in Spitsbergen within a single sequence. It is clear however that they are characteristic of the uppermost beds of the Botneheia Formation, where phosphorite nodules are abundant. I consider this interval as the *Nathorstites* Beds corresponding to the *macconnelli* and *lindstroemi* zones of northeastern Asia.

Deposits occurring in the top portion of the Botneheia Formation of Spitsbergen between the nodular interbed (the *Indigirites tozeri* Zone) and below the upper phosphorite conglomerate (the *Nathorstites* Beds) are as thick as 16 m in the eastern areas of the island. They exhibit two levels yielding ammonoids *Protrachyceras* sp., bivalves *Daonella* ex gr. *subarctica* Popow, and crinoids *Traumatocrinus*. The lower one also yields ptychitid remains of unclear generic affinity. I consider this interval of the sequence as beds with *Protrachyceras* and *Daonella* ex gr. *subarctica* and correlate them conditionally with the *maclearni* Zone of northeastern Asia. This seems to be reasonable, because the last ptychitids detectable in the *maclearni* Zone are missing from overlying beds in Asian sections (Dagys and Konstantinov, 1995).

Table 2. Correlated biostratigraphic zonation of the Ladinian Stage in northeastern Asia, British Columbia, and Southern Alps

Stage	Substage	Ammonoid zones and subzones				
		Northeastern Asia (Dagys and Konstantinov, 1995)	British Columbia (Tozer, 1994)		Southern Alps (Mietto and Manfrin, 1995)	
Ladinian	upper	*Nathorstites lindstroemi*	*Frankites sutherlandi*	*Asklepioceras laurenci*	*Protrachyceras*	*Frankites regoledanus*
		Nathorstites macconnelli		*Frankites glaber*		
		Nathorstites maclearni	*Maclearnoceras maclearni*	*Maclearnoceras ensio*		*"Protrachyceras" neumayri*
				Anolcites angustus		
				Anolcites impolitus		*Protrachyceras longobardicum*
		Indigirites krugi	*Meginoceras meginae*	*Meginoceras aylardi*		
				Silenticeras hatae		*Protrachyceras gredleri*
		Tsvetkovites neraensis		*Meginoceras triviale*		
		Tsvetkovites constantis	*Tuchodiceras poseidon*			*Protrachyceras margaritosum*
	lower	*Eonathorstites oleshkoi*	*Eoprotrachyceras matutinum*		*Eoprotrachyceras*	*Eoprotrachyceras recubariense*
						Eoptotrachyceras curionii

The *lindstroemi* Zone was recently distinguished in the Bear Island (Dagys *et al.*, 1993), where it yields *Nathorstites lindstroemi* Böhm, *Daxatina canadensis* (Whiteaves), *"Clionites" barentsi* Böhm, "Cl." *spinosus* Böhm, and *Paracladiscites* sp. Owing to the present index species, the unit is an equivalent of the synonymous zone in northeastern Asia.

Arctic Canada. In the Sverdrup basin, deposits of the Ladinian Stage are known as constituents of the Blaa-Mountain and Shei-Point formations (Tozer, 1961). Very rare Ladinian ammonoids are confined here to particular, very thin horizons.

The *Daonella frami* Beds in the lower part of the stage are widespread and traceable in marginal and axial zones of the Sverdrup basin. Usually, they yield only the index species *Daonella frami* Kittl. that coexists with ammonoids *Longobardites* sp. indet., *Protrachyceras* sp. indet., and *Ptychites* (= *Aristoptychites*) *nanuk* Tozer. This level can be correlated in a tentative manner only. The specimen of *Longobardites* sp. indet from the *Daonella frami* Beds (Tozer, 1994, Plate 68, fig. 1) is poorly preserved. Nevertheless, its lobe line that shows the acute phylloid saddles and individualized central denticles in the distinctly dentate lobes suggests a certain similarity with the species *Tsvetkovites constantis* (Archipov). In opinion of Weitschat and Lehmann (1983), ptychitids from the beds belong to the genus *Aristoptychites* being similar to the Siberian species *Aristoptychites kolymensis* (Kiparisova). In northeastern Asia, representatives of this genus appear for the first time in the *neraensis* Zone, and *A. kolymensis* is characteristic of the *krugi* and *maclearni* zones.

The *Nathorstites* Beds are known in the upper part of the Ladinian Stage of Canadian Arctic areas (Tozer, 1961, 1967; Silberling and Tozer, 1968). The recent revision of nathorstitids (Tozer, 1994; Dagys and Konstantinov, 1997) showed that only one of pictured specimens of *Nathorstites macconnelli* from the beds (Tozer, 1961, Plate 22, fig.7) represents this taxon. Two other specimens (Tozer, 1961, Plate 22, figs. 5 and 6) coexisting with *Procladiscites* (= *Sphaerocladiscites*) cf. *martini* (Smith) in the lower Shale Member of the Blaa-Mountain Formation of the Ellesmere Island have swollen cadicone shells with the well-developed umbilical shoulder. In their lobe line, saddles are oval, and lobe denticles are underdeveloped. All these features are typical of *Nathorstites lindstroemi*, and both specimens are classed with this taxon (Dagys and Konstan-

tinov, 1997). Thus, we can distinguish in Arctic Canada two Ladinian levels distinctly corresponding to the *macconnelli* and *lindstroemi* zones of northeastern Asia. In addition, the beds under consideration may also span the *maclearni* Zone.

Franz Josef Land. In this archipelago, the Ladinian Stage is represented by alternating members of shale, siltstone, and sandstone, the total thickness of which (if we ignore the intercalated intrusive bodies) varies from 870 to 1085 m according to data of deep parametrical boreholes (Preobrazhenskaya *et al.*, 1985). Bivalves are principal forms of macrofauna detected in core sections. In the borehole section Severnaya, where basal beds of the upper Ladinian Substage are composed of dark gray to black shales with pyrite, phosphate–siderite, and carbonate nodules, the *Daonella* shells coexist at the depth level of 2331.8 m with ammonoids defined as *Nathorstites* cf. *lenticularis* (Whiteaves). The pictured specimen from this level (Korchinskaya, 1985, Plate 5, fig. 6) shows the well-preserved sculptural elements on lateral sides, namely the radial folds and threads sharply bent backward approximately in the middle of the whorl height. Growth lines like these are untypical of *Nathorstites* forms, *Nathorstites lenticularis* (= *Nathorstites macconnelli*) included, as the latter lack folds on lateral sides and show threads curving forward by approaching the ventral side. The above sculptural elements are characteristic of the genus *Indigirites*, and the specimen under consideration can be definitely classed with *Indigirites* cf. *krugi* Popow. Consequently, the Borehole Severnaya penetrated in the eastern part of the archipelago a stratigraphic equivalent of the *Indigirites krugi* Zone of northeastern Asia.

CORRELATION OF LADINIAN DEPOSITS IN NORTHEASTER ASIA, BRITISH COLUMBIA, AND SOUTHERN ALPS

As is shown above, it is impossible, owing to the distinct provincialism, to correlate in a simple manner the Ladinian ammonoid zonations established in the Boreal and Tethyan regions. The key area for such a correlation is the northeastern part of British Columbia, where Ladinian ammonoids apparently evolved within the past ecotone between the Boreal and Tethyan paleobiogeographic regions and represented the mixed fauna.

British Columbia. On the basis of very complete ammonoid successions studied in the region, Tozer (1967) and Silberling and Tozer (1968) suggested the detailed ammonoid zonation for the Ladinian Stage divided into five zones. The lower Ladinian Substage was initially considered as corresponding to the *Protrachyceras subasperum* and *Progonoceratites poseidon* zones. Later, the *poseidon* Zone was attributed to the upper Ladinian Substage (Tozer, 1981), because there were found *Protrachyceras* forms similar to *P. longobardicum* Mojsisovics from the *Protrachyceras archelaus* Zone of the Alpine region. In his recent fundamental book on ammonoid faunas, Tozer (1994) considerably refined the Ladinian ammonoid zonation in British Columbia, though without its subdivision into substages. He revised the generic affinity of some ammonoids and changed the nomenclature of particular zones considering *Eoprotrachyceras matutinum* Tozer as the index species of the lowermost zone and attributing the index species of the overlying *poseidon* Zone to the new genus *Tuchodiceras*. In addition, the *Meginoceras meginae, Maclearnoceras maclearni*, and *Frankites sutherlandi* zones were divided into subzones. In total, the Ladinian ammonoid zonation in British Columbia includes now 13 biostratigraphic units ranked as zones and subzones.

Ladinian ammonoids from the region under consideration are very diverse and belong to 35 genera (Tozer, 1994). Only eight of these genera, namely *Eonathorstites, Tsvetkovites* (*"Indigirites" freboldi* Tozer), *Indigirites, Nathorstites, Arctoptychites, Longobardites, Proarcestes*, and *Lobites*, are known from Ladinian deposits of northeastern Asia. Three last genera of a wide stratigraphic range are cosmopolitan and useless for the detailed correlation analysis. Suggesting here the correlation scheme for the Ladinian ammonoid zonations in British Columbia and northeastern Asia, I used available data on stratigraphic ranges of tsvetkovitids (genera *Eonathorstites* and *Tsvetkovites*), nathorstitids (genera *Indigirites* and *Nathorstites*), and ptychitids (genus *Arctoptychites*).

The *maclearni* Zone of British Columbia appears to be well correlative with the synonymous zone of northeastern Asia, because they both yield the common species *Nathorstites maclearni* Tozer. Species *Indigirites boehmi* Tozer, the younger synonym of *Indigirites krugi* Popow (Dagys and Konstantinov, 1997), is abundant in two upper subzones of the *meginae* Zone. Consequently, the *Silenticeras hatae* and *Meginoceras aylardi* subzones of the *meginae* Zone in British Columbia can be correlated with the *Indigirites krugi* Zone in northeastern Asia. The greater upper part of the *Tuchodiceras poseidon* Zone seems to be an equivalent of the *Tsvetkovites constantis* Zone, since the genus *Arctoptychites* is typical of these stratigraphic intervals enclosing as well the *Tsvetkovites* species similar in morphology of their relatively narrow shells: *Ts. freboldi* (Tozer) from the *poseidon* Zone and *Ts. constantis* (Archipov) from the *constantis* Zone. The lower part of the *poseidon* Zone is correlative, as we will see below, with the *Eonathorstites oleshkoi* Zone. The *Meginoceras triviale* Subzone of the *meginae* Zone is situated above the *poseidon* Zone, but below the *hatae* and *aylardi* subzones. According to this stratigraphic position, it may correspond to the *Tsvetkovites neraensis* Zone. I consider the *Frankites sutherlandi* Zone of British Columbia as spanning the range of the *Nathorstites macconnelli* and *N. lindstroemi* zones of northeastern Asia. This conclusion is substantiated by occurrence of *N. macconnelli* (Whiteaves) in the upper *Asklepioceras laurenci* Subzone of the *sutherlandi*

Zone. Analyzing data on composition and relative position of ammonoid assemblages presented by Tozer (1994), I assume that *N. macconnelli* does not occur as high in the sequence as the upper beds of the *sutherlandi* Zone, where characteristic forms are trachyceratids *Daxatina laubei* Tozer and *D. canadensis* (Whiteaves). In the Bear Island of the Svalbard Archipelago, the last species coexists with *Nathorstites lindstroemi* Böhm (Böhm, 1903; Dagys *et al.*, 1993). Accordingly, an upper part of the *laurenci* Subzone of the *sutherlandi* Zone is correlative with the *lindstroemi* Zone, and the lower part of this subzone corresponds to the *macconnelli* Zone. I also think with a reservation that the latter, according to its position above the *Nathorstites maclearni* Beds in northeastern Asia, may also include an equivalent of the *Frankites glaber* Subzone of the *sutherlandi* Zone.

Correlation between the lowermost Ladinian beds in British Columbia and northeastern Asia is very complicated. In the last region, the index species of the lowermost Ladinian zone was originally described as *Longobardites oleshkoi* Archipov (Archipov, 1974). Revising the described species, Dagys and Konstantinov (1997) emphasized that it had the ventral keel at the early stages of growth. Owing to this feature and numerous, highly dentate lobes, the form in question cannot be attributed to *Longobardites* or *Intornites* genera and must be classified as a species of the genus *Eonathorstites*. In British Columbia (Tozer, 1994), representatives of this genus have been discovered in association with *Ptychites hamatus* Tozer, *Protrachyceras sikanianum* McLearn, and *Metatirolites withrowi* Tozer within a single section below the occurrence level of *Tsvetkovites freboldi* (Tozer). Tozer conditionally included the respective strata into the *poseidon* Zone and mentioned that they may correspond to an individual subzone. The noteworthy fact is that the beds bearing *Eonathorstites* forms in British Columbia are unknown as members of sections exhibiting the lower *Eoprotrachyceras matutinum* Zone of the Ladinian Stage. As we do not know relations between the *Eonathorstites* level and *matutinum* Zone, I consider the *oleshkoi* Zone, which is situated below the first occurrence level of *Tsvetkovites* forms in both regions, as corresponding to the lower *poseidon* interval coupled with the whole range of the *matutinum* Zone. Considering the lower *poseidon* strata as correlative with the *oleshkoi* Zone, I used as an evidence the occurrence of *Eonathorstites* forms in both subdivisions. The traditional scheme, where the *oleshkoi* Zone is correlated with the lower ammonoid zone of the Ladinian Stage in British Columbia (Dagys *et al.*, 1979, 1991; Konstantinov, 1991), is more hypothetical, because it is based on stratigraphic position of the unit between the occurrence levels of last *Frechites* and first *Tsvetkovites* forms.

Southern Alps. This Alpine region represents the stratotype area of the Ladinian Stage, where stratigraphic investigations ceased long ago, when the stage was divided into the lower (Fassan) and upper (Longobardian) substages corresponding to the *Eoprotrachyceras curioni* and *P. archelaus* zones, respectively (*Obshchaya shkala...*, 1984). However, Italian researchers recently discovered new localities of ammonoid faunas and investigated anew the Ladinian type sections. As a result, they elucidated the stratigraphic succession of ammonoid assemblages and suggested the detailed ammonoid zonation for the stage (Mietto and Manfrin, 1995). Being based on the hierarchical principle, the suggested scheme includes two substages, three genus-zones, and ten subzones of distinguished index species. Lower boundaries of all subdivisions are universally defined as the first occurrence levels of indicative genera or index species. Accepting the scheme in general, I feel it necessary to place the lower boundary of the stage at the base of the *Eoprotrachyceras curioni* Zone and correlative units.

Principal for correlation of Ladinian deposits in British Columbia and Southern Alps are data on stratigraphic distribution of trachyceratids, particularly of genera *Eoprotrachyceras, Protrachyceras, Liardites, Maclearnoceras*, and *Frankites*.

The *Eoprotrachyceras* Genus-zone of Southern Alps corresponding in its range to the lower Ladinian (Fassan) Substage correlates with the *matutinum* Zone of British Columbia, because *Eoprotrachyceras* is the common genus of both. Lower boundaries of the *Protrachyceras* Genus-zone in Alps and *poseidon* Zone in Canada are definitely synchronous and mark in two regions the first occurrence level of true *Protrachyceras* forms, which have partite saddles in the lobe line. The ammonoid assemblage from the *"Protrachyceras" neumayri* Subzone includes genera *Maclearnoceras* and *Liardites*. In British Columbia, these genera are characteristic of the *Anolcites angustus* and *Maclearnoceras ensio* subzones of the *maclearni* Zone, and these two units are correlative with the *neumayri* Subzone. Three lower subzones of the *Protrachyceras* Genus-zone (those of *P. margaritosum, P. gredleri*, and *P. longobardicum*) correspond in their stratigraphic interval to the summary range of the *poseidon* and *meginae* zones coupled with the *Anolcites impolitus* Subzone of the *maclearni* Zone of British Columbia. The more precise correlation of these biozonal subdivisions is now impossible on the stipulation that *Protrachyceras sikanianum* McLearn, the only form of the genus occurring in the *poseidon, meginae*, and *maclearni* zones of British Columbia, is highly variable in morphology, being represented in the whole distribution interval by both the involute shells resembling those of *P. longobardicum* Mojsisovics and the evolute specimens similar to *P. archelaus* Mojs. (Tozer, 1994). The upper *Frankites regoledanus* Subzone of the *Protrachyceras* Genus-zone in Southern Alps bears *Lobites ellipticus* Hauer and genera *Frankites, Asklepioceras*, and *Muensterites*, which are also characteristic of the correlative *sutherlandi* Zone in Canada. This is also evident from the fact that the first Carnian forms of

the genus *Trachyceras* appear in strata overlying the last correlation level in Alps (Urlichs, 1994; Mietto and Manfrin, 1995) and Canada (Tozer, 1994).

Finally, the *macconnelli* and *lindstroemi* zones of northeastern Asia are correlative with the *sutherlandi* Zone of British Columbia and also with the *regoledanus* Subzone of the *Protrachyceras* Genus-zone of Southern Alps. Then, the *Nathorstites maclearni* and *Maclearnoceras maclearni* zones correlative one to another correspond to the *"Protrachyceras" neumayri* Subzone combined with the upper part of the *Protrachyceras longobardicum* Subzone. Lastly, the *oleshkoi, constantis, neraensis*, and *krugi* zones of northeastern Asia can be correlated, via sections of British Columbia, with the summary stratigraphic range spanning the *Eoprotrachyceras* Genus-zone coupled with *margaritosum, gredleri*, and *longobardicum* subzones of the *Protrachyceras* Genus-zone in Southern Alps.

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research, project no. 97-05-65290.

Reviewers A.A. Shevyrev and A.S. Alekseev

REFERENCES

Anisian–Ladinian Boundary Field Workshop, Southern Alps–Balaton Highlands, 27 June–4 July, 1993, Milano, 1993.

Arkhipov, Yu.V., *Stratigrafiya triasovykh otlozhenii Vostochnoi Yakutii* (Triassic Stratigraphy of Eastern Yakutiya), Yakutsk: Yakutsk Knizhn. Izd., 1974.

Böhm, J., Über die Obertriasische Fauna der Böreninsel, *Kgl. Svenska Veternkaps-Akad. Handl.*, 1903, vol. 37, no. 3, pp. 1–76.

Bychkov, Yu.M., Nathorstitidae of the Northeastern USSR, in *Materialy po geologii i poleznym iskopaemym Severo-Vostoka SSSR* (Materials on Geology and Mineral Deposits of the Northeastern USSR), Magadan: Magadan Knizhn. Izd., 1982, no. 26, pp. 26–37.

Dagys, A.S. and Konstantinov, A.G., A New Zonal Scheme of the Boreal Ladinian, *Albertiana*, 1992, no. 10, pp. 17–21.

Dagys, A.S. and Konstantinov, A.G., New Zonation Scheme of the Ladinian Stage for Northeastern Asia, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 121–127.

Dagys, A.S. and Konstantinov, A.G., Revised Nathorstitidae (Ammonoidea) of Northeastern Asia, *Paleontol. Zh.*, 1997, no. 5, pp. 41–49.

Dagys, A.S., Arkhipov, Yu.M., and Bychkov, Yu.M., *Stratigrafiya triasovoi sistemy Severo-Vostoka Azii* (Stratigraphy of Triassic System in Northeastern Asia), Moscow: Nauka, 1979.

Dagys, A.S., Konstantinov, A.G., and Sobolev, E.S., Materials for the Boreal Ladinian Biostratigraphy, in *Biostratigrafiya i paleontologiya triasa Sibiri* (Triassic Biostratigraphy and Paleontology), Novosibirsk: Ob'ed. Inst. Geol. Geofyz. Mineral. Sib. Otd. Ross. Akad. Nauk, 1991, pp. 74–96.

Dagys, A.S. and Tozer, E.T., Triassic Correlation between Northern Canada and Siberia, *Geol. Geofiz.*, 1989, no. 6, pp. 3–9.

Dagys, A. and Weitschat, W., Correlation of the Boreal Triassic, *Mitt. Geol. Paläontol. Inst. Univ. Hamburg*, 1993, vol. 75, pp. 249–256.

Dagys, A., Weitschat, W., Konstantinov, A., and Sobolev, E., Evolution of the Boreal Marine Biota and Biostratigraphy at the Middle/Upper Triassic Boundary, *Mitt. Geol. Paléontol. Inst. Univ. Hamburg.*, 1993, vol. 75, pp. 193–209.

Frebold, H., Faunistisch–stratigraphische Untersuchungen über die Trias Spitzbergens und der Edge Insel, *Abh. Naturwiss.* (Hamburg), 1929, vol. 22, nos. 3–4, pp. 295–312.

Konstantinov, A.G., *Biostratigrafiya i ammonoidei verkhnego aniziya severa Sibiri* (Upper Anisian Biostratigraphy and Ammonoids of Northern Siberia), Novosibirsk: Nauka, 1991.

Korchinskaya, M.V., Distribution of Nathorstitidae in Triassic Deposits of Svalbard, in *Mezozoiskie otlozheniya Sval'barda* (Mesozoic Deposits of Svalbard), Leningrad: Nauchn.–Issled. Inst. Geol. Arktiki, 1972, pp. 64–74.

Korchinskaya, M.V., *Ob"yasnitel'naya zapiska k stratigraficheskoi skheme mezozoya (trias) Sval'barda* [Explanatory Note to the Mesozoic (Triassic) Stratigraphic Scheme of Svalbard], Leningrad: Sevmorgeologiya, 1982.

Korchinskaya, M.V., Faunal Characteristics of Triassic Deposits in the Franz Josef Land, in *Stratigrafiya i paleontologiya mezozoiskikh osadochnykh basseinov Severa SSSR* (Stratigraphy and Paleontology of Mesozoic Sedimentary Basins in the Northern USSR), Leningrad: Sevmorgeologiya, 1985, pp. 16–27.

Mietto, P. and Manfrin, S., A High Resolution Middle Triassic Ammonoid Standard Scale in the Tethys Realm. A Preliminary Report, *Bull. Soc. Geol. Fr.*, 1995, vol. 166, no. 5, pp. 539–563.

Mojsisovics, E., Die Cephalopoden der Mediterranen Triasprovinz, *Abh. Geol. Reichsanst. Wien*, 1882, B. 10, pp. 1–322.

Obshchaya shkala triasovoi sistemy SSSR (The General Triassic Scale for the USSR), Leningrad: Vses. Geol. Inst., 1984.

Preobrazhenskaya, E.N., Shkola, I.V., and Korchinskaya, M.V., Triassic Stratigraphy of the Franz Josef Land Based on the Parametric Drilling Data, in *Stratigrafiya i paleontologiya mezozoiskikh osadochnykh basseinov Severa SSSR* (Stratigraphy and Paleontology of Mesozoic Sedimentary Basins in the Northern USSR), Leningrad: Sevmorgeologiya, 1985, pp. 5–15.

Shevyrev, A.A., *Triasovye ammonoidei* (Triassic Ammonoidea), Moscow: Nauka, 1986.

Silberling, N.J. and Tozer, E.T., Biostratigraphic Classification of the Marine Triassic in North America, *Spec. Pap. Geol. Soc. Am.*, 1968, no. 110, pp. 1–63.

Stolley, E., Zur Kenntniss der arktischen Trias, *Neues Jahrb. Mineral. Geol. Paläontol.*, 1911, vol. 1, pp. 114–126.

Tozer, E.T., Triassic Stratigraphy and Faunas, Queen Elizabeth Islands, Arctic Archipelago, *Mem. Geol. Surv. Can.*, 1961, no. 316, pp. 1–116.

Tozer, E.T., A Standard for Triassic Time, *Bull. Geol. Surv. Can.*, 1967, no. 156, pp. 1–103.

Tozer, E.T., Triassic Ammonoidea: Geographic and Stratigraphic Distribution, *The Ammonoidea*, London: Academic, 1981, pp. 65–100.

Tozer, E.T., Canadian Triassic Ammonoid Faunas, *Bull. Geol. Surv. Can.*, 1994, no. 467, pp. 1–663.

Urlichs, M., *Trachyceras* Laube 1869 (Ammonoidea) aus dem Unterkarn (Obertrias) der Dolomiten (Italien), *Stuttgart. Beitr. Natur., Ser. B.*, 1994, vol. 217, pp. 1–55.

Weitschat, W. and Dagys, A.S., Triassic Biostratigraphy of Svalbard and a Comparison with NE-Siberia, *Mitt. Geol. Paläontol. Inst. Univ. Hamburg*, 1989, vol. 68, pp. 179–213.

Weitschat, W. and Lehmann, U., Stratigraphy and Ammonoids from the Middle Triassic Botneheia Formation (*Daonella* Shales) of Spitsbergen, *Mitt. Geol. Paläontol. Inst. Univ. Hamburg*, 1983, vol. 54, pp. 27–54.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 362–371. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 49–58.
Original Russian Text Copyright © 2000 by Bragin, Egorov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Middle–Late Triassic Radiolarians from the Dzhugadzhak Section (the Omolon Massif)

N. Yu. Bragin* and A. Yu. Egorov**

**Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*
***PGO "Aerogeologiya," Leninskii pr. 35, Moscow, 117071 Russia*
Received June 9, 1997; in final form, September 11, 1998

Abstract—Radiolarians were found in the upper Anisian, upper Ladinian, and lower Carnian deposits of the Omolon massif. Their assemblages are less diverse than the coeval Mediterranean assemblages but very similar to the Middle Triassic assemblages of New Zealand. The identified cosmopolitan species of the assemblages enable correlation between Triassic deposits in the high and low latitudes.

Key words: *Triassic, Omolon massif, stratigraphy, correlation, paleobiogeography, radiolarians.*

INTRODUCTION

Radiolarians represent one of the fossil groups studied inadequately. This especially concerns the Mesozoic radiolarian assemblages from the high-latitude (boreal) areas, particularly from Triassic deposits. Abundant data on compositions of Triassic radiolarian assemblages and vertical ranges of individual taxa in the tropical belt (the Mediterranean region, Japan, the Far East of Russia, western areas of the United States and Mexico) were used to elaborate several valid stratigraphic schemes (Bragin, 1991; Carter, 1993; Kozur and Mostler, 1994; Yao, 1990). On the contrary, investigation of their boreal assemblages that was started recently yielded so far scanty information. However, the high-latitude radiolarian assemblages are very promising for regional paleogeographic reconstructions and for solving the fundamental problem of correlation between deposits accumulated in different paleoclimatic zones. In this respect, the radiolarian-bearing Triassic deposits in boreal areas of northeastern Asia are of great interest.

At present, radiolarians are known to occur in the bed succession exposed along the Dzhugadzhak River in the Omolon massif (figure). Hemipelagic Triassic deposits of the region accumulated at a great distance from the shore. They are represented predominantly by clay, mudstone, and rare limestone layers yielding peculiar assemblages of sculpture-lacking ammonoids, pseudoplanktonic bivalves, and radiolarians. Remains of benthic organisms occur sporadically, being especially scarce in the Middle Triassic and Carnian deposits (Dagys *et al.*, 1979, 1991; Dagys and Konstantinov, 1995; Egorov *et al.*, 1987). Radiolarians are concentrated at several stratigraphic levels of the succession and sometimes occur in the neighboring beds. In addition to their paleontological value, these finds extend our knowledge on the Mesozoic boreal assemblages of radiolarians and are useful for various paleoclimatic and tectonic reconstructions.

DESCRIPTION OF THE SECTION

The Triassic reference section is located in the middle courses of the Dzhugadzhak River (the tributary of the Korkodon River in the Kolyma River basin) within the southwestern Omolon massif. The studied outcrops are located at the left side of the Dzhugadzhak River valley immediately above to the Zhil'nyi Creek mouth. The section was described more than once (Goduntsov *et al.*, 1968; Dagys *et al.*, 1979). In this article, we present our own, more detailed description. In the local stratigraphic scheme, the deposits in question are included into the Triassic Dzhugadzhak Formation (Bychkov *et al.*, 1996). Determinations of macrofauna were performed by A.G. Konstantinov (ammonoids), E.S. Sobolev (nautiloids), N.I. Kurushin (bivalves), and A.S. Dagys (brachiopods).

The Triassic section at the Dzhugadzhak River includes the following units (from the base upward, see figure).

The Triassic system. The Dzhugadzhak Formation

The Lower Triassic

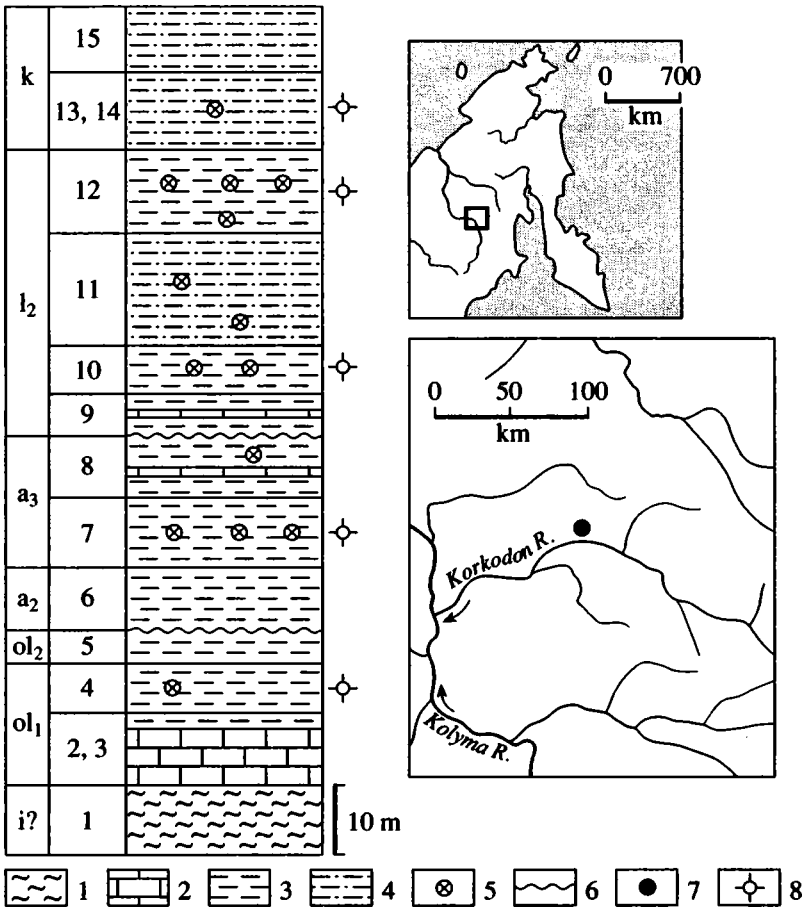
The Induan Stage (?)

(1) Light gray clay bearing small poorly preserved Rhynchonellidae (10 m thick).

Olenekian Stage

Lower substage

(2) Light gray finely crystalline limestones, highly bituminous, flaggy, and massive, with rare interbeds of brownish gray calcareous mudstones (7 m thick).



Geographic position and lithostratigraphy of the Triassic Dzhugadzhak section and occurrence levels of radiolarians: (1) clay; (2) limestone; (3) mudstone; (4) siltstone; (5) phosphatic nodules; (6) unconformity; (7) study site; (8) level with radiolarians. Symbols for Triassic stages in the first column: (i) Induan, (ol) Olenekian, (a) Anisian, (l) Ladinian, (k) Carnian; bed numbers are marked in the second column.

(3) Gray to dark gray and brownish gray laminated mudstones with interbeds (0.1 m) of gray bituminous clayey limestone and brownish gray silty clay (3 m thick).

(4) Gray and dark gray finely bedded mudstones with interbeds (0.1–0.2 m) of black bituminous shale; the rocks enclose small phosphatic concretions with unidentifiable spherical radiolarians (6.5 m thick).

Beds 2–4 contain conodonts and bivalve mollusks indicative of the *hedenstroemi* and *tardus* zones of the lower Olenekian Substage.

The upper substage

(5) Dark gray finely bedded mudstones with abundant *Claraia aranea* Tozer (4 m thick).

Middle Triassic

Anisian Stage

Middle substage

(6) Dark gray and black thinly bedded mudstones enclosing ammonites *Czekanowskites decipiens* (Mojs.); the bed shows the erosional lower contact. Lower Anisian deposits are missing (8 m thick).

Upper substage

(7) Dark gray and black mudstones with abundant phosphatic concretions containing ammonites *Amphipopanoceras dzenginense* Arch. and radiolarians *Archaeothamnulus* (?) sp., *Entactinia* sp., *Oertlispongus* sp., *Pseudostylosphaera* (?) sp. ex gr. *P. fragilis* (Bragin), *P.* (?) sp., Spongodiscoidea (?) gen. indet. (spherical spongy shells with large inner chamber, but without spicule), *Spongopallium* (?) sp., *Stauracontium* (?) sp., and *Triassocampe* (?) sp. (9 m thick).

(8) Dark gray and black mudstones and siltstones with phosphatic concretions and interbeds of gray fine-grained calcareous sandstone, black bituminous shale, and dark brownish limestone bearing the ammonite assemblage with *Parafrechites sublaqueatus* Bytschkov (the uppermost Anisian); radiolarians are also abundant but poorly preserved (8 m thick).

Stratigraphic hiatus corresponding to the missing lower Ladinian deposits.

Ladinian Stage

Upper substage

(9) Black laminated mudstones intercalated with gray, yellow and white clays, and with dark gray bituminous limestones bearing abundant bivalves *Daonella prima* Kipar. (5.5 m thick).

(10) Dark gray and black mudstones and bituminous shales enclosing abundant phosphatic concretions with ammonites *Arctoptychites omolojensis* Archipov (in the lower 2.5 m), *Arctogymnites* sp. cf. *A. spectori* Arch., and *Indigirophyllites oimekonensis* Popov (5–5.5 m above the bed base), algae *Tasmanites* sp., and radiolarians *Archaeocenosphaera* sp., *Entactinia* sp., *Ferresium* (?) sp., *Glomeropyle boreale* Bragin, *Hindeosphaera* sp. ex gr., *H. spinulosa* (Nakaseko et Nishimura), *H.* sp., *Hozmadia* (?) sp., *Laxtorum* (?) sp., *Pachus* (?) sp., *Parentactinia pygnax* Dumitrica, *P.* sp. cf. *P. inerme* Dumitrica, *Praenanina* sp., *Poulpus* sp., *Silicarmiger costatus costatus* Dumitrica, Kozur et Mostler, *S.* sp. cf. *S. latus* Kozur et Mostler, Spongodiscoidea gen. indet. (spongy spheres analogous to those from Bed 7), *Spongopallium* sp. aff. *S. koppi* (Lahm), and *Stauracontium* (?) sp. (6.5 m thick).

(11) Alternating layers of black bituminous calcareous siltstone (0.5 m) and yellow to white clay (up to 0.1 m) containing rare phosphatic concretions with *Arctophychites* sp., *Indigirophyllites* sp., *Gryponautilus* sp. ex gr., *G. kegalensis* Sob. (1–1.2 m above the base), *Nathorstites* sp. cf. *N. mclearni* Tozer, and *Aristoptychites kolymensis* Kipar. (13.3 m above the bed base) (15 m thick).

(12) Black foliated calcareous mudstones enclosing abundant globular phosphatic concretions with macrofossils *Nathorstites mclearni* Tozer, *Aristophychites kolymensis* Kipar. (1 or 2 m above the base), *Sphaerocladiscites omolojensis* Bytschkov, *Indigirophyllites oimekonensis* Popov, *Nathorstites mcconnelli* (White), *Sinuplicorhynchia kegalensis* Dagys (2.8–9.7 m above the base), *Nathorstites lindstroemi* Bohm, and *Sphaerocladiscites omolojensis* Bytschkov (9.7–10.3 m above the bed base); associated radiolarians are *Archaeocenosphaera* sp., *Pseudostylosphaera omolonica* sp. nov., and *Ferresium* (?) sp. (10.5 m thick).

(13) Alternating black soft mudstones (up to 0.5 m) and denser platy calcareous shales (up to 0.1 m); both rock varieties contain abundant phosphatic concretions with ammonites *Mathorstites lindstroemi* Bohm and *Sphaerocladiscites omolojensis* Bytschkov (1.3–2.3 m above the bed base), which associate higher (4.1–6 m above the bed base) with nautiloids *Proclydonautilus aniamensis* (Shim.) (11.6 m thick).

Upper Triassic

Carnian Stage

(14) Dark gray bituminous–calcareous siltstone with poorly sorted clastics, reptilian bones, shell detritus, and fucoids. Abundant phosphatic concretions contain *Discophyllites* sp., *Stolleites* sp. cf. *S. tenuis* (Stolley), *Proclydonautilus aniamensis* (Shim.), *Cenoceras boreale* Dagys et Sob. (0–0.3 m above the bed base), *Proclydonautilus aniamensis* (Shim.), *Pennospiriferina popovi* Dagys, *Pennospiriferina (Dentospiriferina) costata* Dagys, *P. (D.) pepeliaevi* Dagys (1.1–3 m above the bed base), and *Holcorhynchia tibetica* (Bitt.) (4.5 m above the bed base) associated with radiolarians *Pseudostylosphaera omolonica* sp. nov. and *Ferresium* sp. (2 m thick).

(15) Black calcareous foliated siltstones with scarce phosphatic nodules containing *Discophyllites taimyrensis* Popov, *Cenoceras boreale* Dagys et Sob., *Pennospiriferina (Dentospiriferina) costata* Dagys, *Planirhynchia yakutica* Dagys (4.5 or 4.9 m above the bed base) and radiolarians *Pseudostylosphaera* sp. (10 m thick).

(16) Dark gray, bioturbated massive to flaggy calcareous siltstones with rare carbonate and phosphatic nodules enclosing *Discophyllites taimyrensis* Popov, and *Pennospiriferina (Dentospiriferina) costata* Dagys (5.3 m above the bed base); the apparent thickness is 8 m.

CORRELATION OF TRIASSIC RADIOLARIAN ASSEMBLAGES

The Triassic deposits of the Omolon massif accumulated in the open sea settings and yield radiolarian assemblages considerably changing upward in their composition. Consequently, radiolarians can be considered in this case as a paleontological group important for biostratigraphy of the boreal Triassic. In addition, the Triassic radiolarian assemblages from the Omolon massif significantly differ from radiolarians of the Koryak Upland, Sikhote-Alin, and Sakhalin, which supposedly originated under the tropical conditions (Bragin, 1991). For instance, the radiolarian assemblages of the boreal Middle Triassic succession at the Dzhugadzhak River are absolutely devoid of species representing the tropical families Eptingiidae, Muelleritortiidae and Oertlispongiidae, genus *Yeharaia*, and other groups. The genus *Triassocampe* occurs here sporadically. These data indicate a considerable biogeographic differentiation between radiolarian faunas of the Middle Triassic time. Accordingly, there are two main objectives of the study. First, we have to analyze vertical ranges of the distinguished assemblages, to subdivide the bed succession on this basis, and to establish facies-dependent variations in abundance and diversity of radiolarians. The second objective is a comparative analysis of coeval boreal and tropical assemblages for evaluation of their correlation potential.

In the Dzhugadzhak section, the oldest radiolarians are those of the upper Olenekian deposits, which yielded only rare and simple spherical forms probably representing Entactiniidae. This is a characteristic feature of the upper Lower Triassic deposits in different regions, where corresponding beds are characterized by similar and taxonomically uniform Entactiniidae assemblages (Sashida, 1983; Bragin, 1991; Sugiyama, 1992; Kozur and Mostler, 1994). Similarly to some other faunal groups of the Early Triassic, distinctions

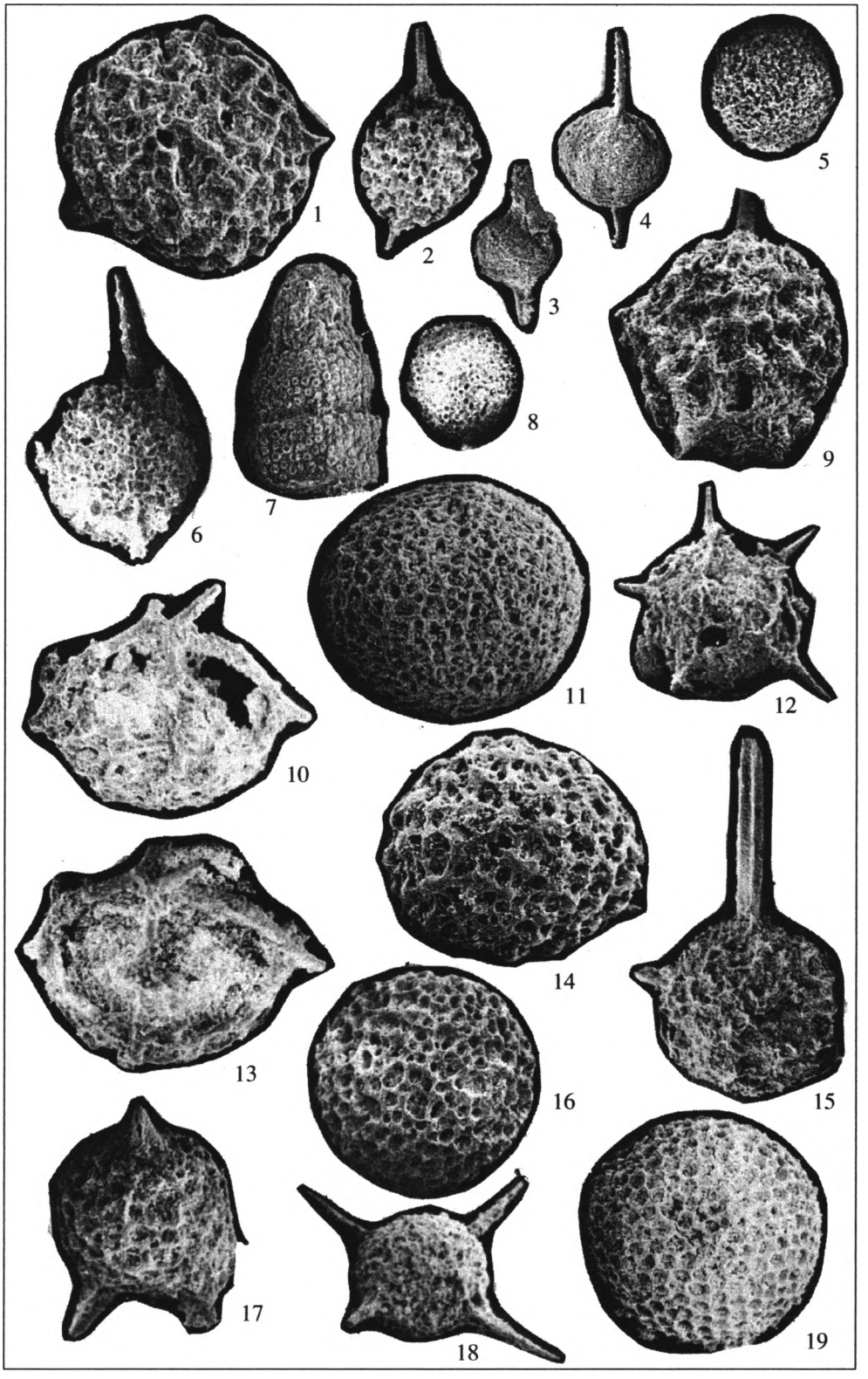


Plate I. Radiolarians from the Middle and Upper Triassic deposits of the Dzhugadzhak River locality (Plates I–IV).
(1, 9) *Entactinia* (?) sp., ×250; (2, 6); *Pseudostylosphaera* (?) sp. ex gr. *P. fragilis* (Bragin), ×100; (3, 4) *Pseudostylosphaera* sp., ×100; (5, 8, 11, 16) *Spongodiscoidea* (?) gen. indet., (5, 8) ×100; (11, 16) ×250; (7) *Triassocampe?* sp., ×250; (10, 13) *Parentactinia* sp. cf. *P. inerme* Dumitrica; ×250; (12) *Sphaerellaria* gen. et sp. indet., ×200; (14) *Praenanina* sp., ×250; (15) *Sphaerellaria* gen. et sp. indet., ×250; (17) *Sphaerellaria* gen. et sp. indet., ×250; (18) *Stauracontium?* sp., ×200; (19) *Archaeocenosphaera* sp., ×250. Specimens 1–8 are from the upper Anisian and 9–19 from the upper Ladinian deposits.

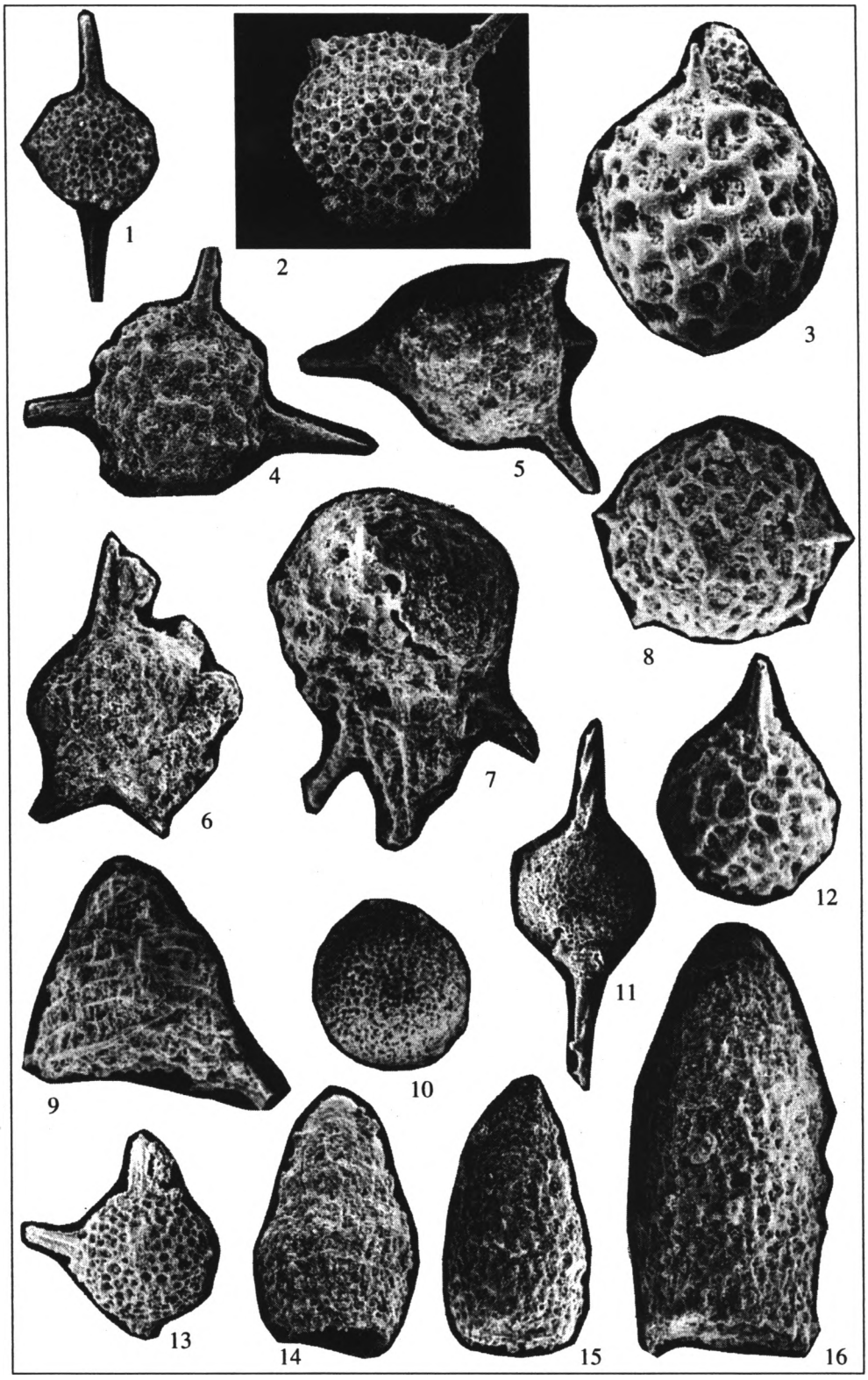


Plate II.

(1, 2) *Pseudostylosphaera* sp.: (1) ×80, (2) ×150; (3, 9) *Hindeosphaera* (?) sp. ex gr. *H. spinulosa* (Nakaseko et Nishimura): (3) ×300, (9) ×200; (4, 5) *Ferresium* (?) sp., ×250; (6) *Sphaerellaria* gen. et sp. indet., ×250; (7) *Hozmadia* (?) sp., ×250; (8) *Poulpus* sp., ×300; (10) *Silicarmiger* sp. cf. *S. latus* Kozur et Mostler., ×250; (11) *Spongodiscoides* (?) gen. indet., ×150; (12) *Spongopallium* sp. aff. *S. koppi* (Lahm), ×250; (13) *Sphaerellaria* gen. et sp. indet., ×150; (14) *Pachus* (?) sp., ×200; (15, 16) *Laxtorum* (?) sp.: (15) ×200, (16) ×320. All radiolarians are from the upper Ladinian deposits.

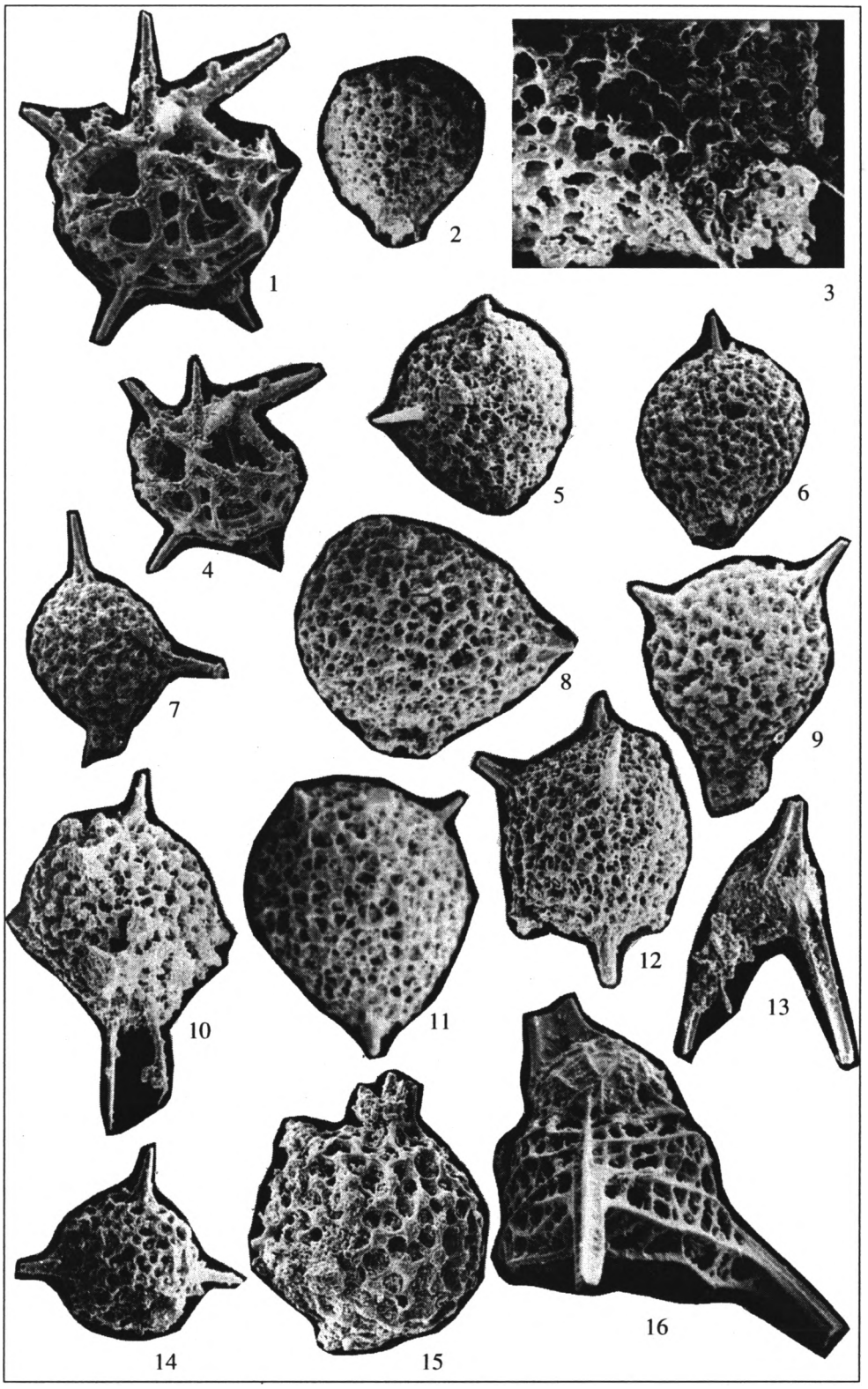


Plate III.

(1, 4) *Parentactinia pygnax* Dumitrica: (1) ×350, (4) ×250; (2, 3, 5–12) *Glomeropyle boreale* Bragin: (2, 3) holotype: (2) ×80, (3) ×250; (5–12) paratypes: (5–7) ×80, (8–12) ×100; (13) *Triassobipedis* sp., ×150; (14) *Sphaerellaria* gen. et sp. indet., ×100; (15) *Ferresium* (?) sp., ×250; (16) *Silicarmiger costatus costatus* Dumitrica, Kozur et Mostler, ×300. All radiolarians are from the upper Ladinian deposits.

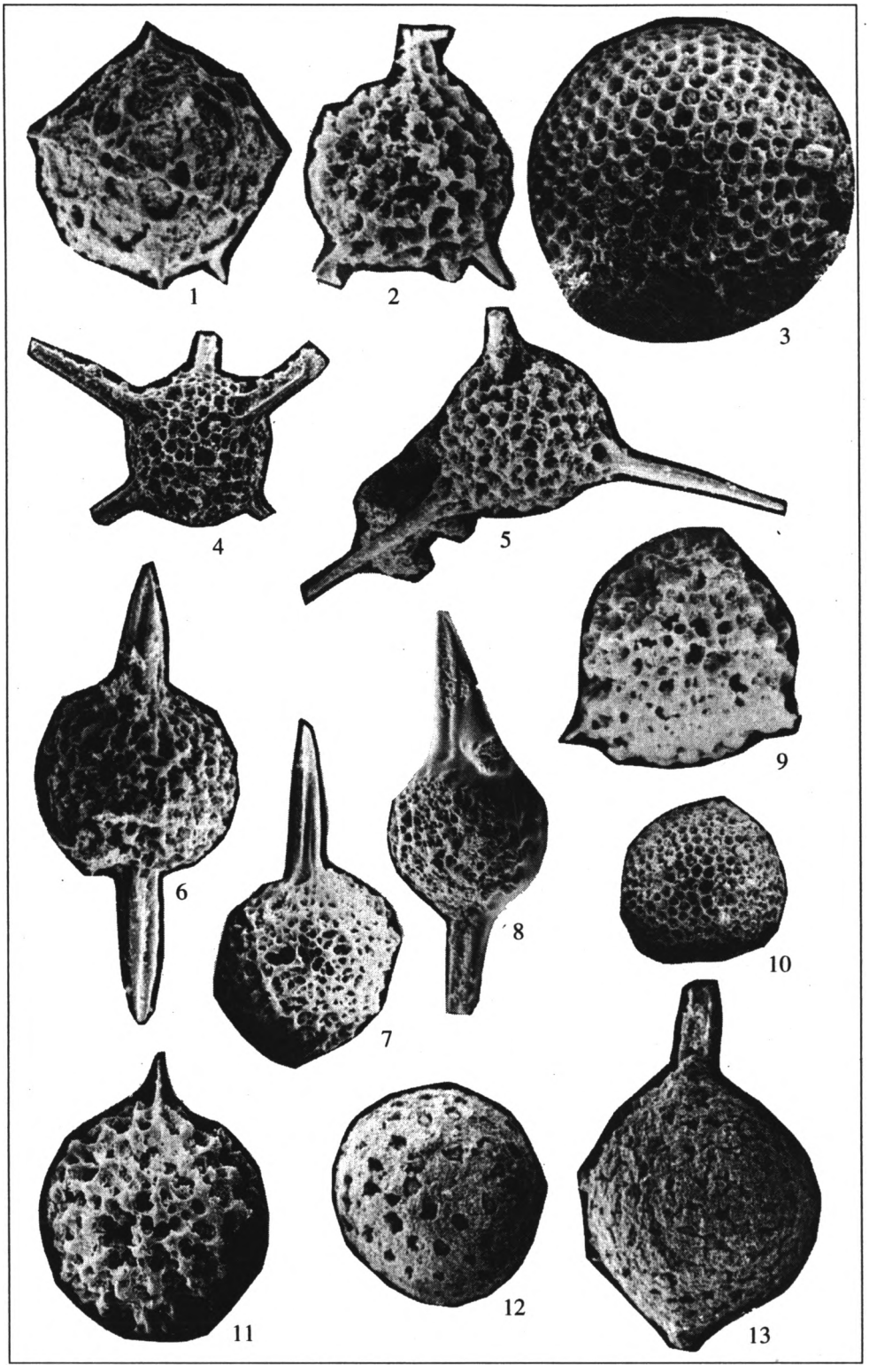


Plate IV.

(1) *Sphaerellaria* gen. et sp. indet., ×200; (2, 5, 6) *Ferresium* sp.: (2, 6) ×250, (5) ×200; (3, 10) *Archaeocenosphaera* sp.: (3) ×300, (10) ×100; (4) *Sphaerellaria* gen. et sp. indet., ×200; (7–9) *Pseudostylosphaera omolonica* sp. nov., ×200; (7) holotype; (11) *Sphaerellaria* gen. et sp. indet., ×250; (12) *Sphaerellaria* gen. et sp. indet., ×250; (13) *Pseudostylosphaera* (?) sp., ×250. Specimens 1–3, 6, 7 are from the upper Ladinian and 4, 5, 8–13 from the lower Carnian deposits.

between boreal and tropical assemblages of radiolarians may be insignificant. Regretfully, the comprehensive analysis and identification of the Early Triassic radiolarians from the Omolon massif is impossible because of their poor preservation.

The upper Anisian deposits of the section yielded the radiolarian assemblage of a low taxonomic diversity, in which representatives of Eptingiidae and spherical forms with spongy walls (Spongodiscoidea gen. indet.) are dominant. Despite the low diversity, these radiolarians are very abundant, locally rock-forming. They may be considered as indicators of an extensive sea transgression at the late Anisian time that was able to sharply increase the plankton productivity and subsequent accumulation of phosphorite and bituminous shales.

The richest radiolarian assemblage is detected in the upper Ladinian deposits, where phosphorites and bituminous shales especially widespread and mark an episode of the extremely high biological productivity. This assemblage is of greatest interest, especially when compared with known assemblages of the same age. The assemblage from the lower part of the upper Ladinian comprises two groups of species: (1) those described earlier from the tropical belt of the Triassic time, and (2) taxa unknown from the tropical regions.

The tropical group includes *Hindeosphaera* sp. ex gr. *H. spinulosa* (Nakaseko et Nishimura), *Parentactinia pygnax* Dumitrica, *P.* sp. cf. *P. inerme* Dumitrica, *Silicarmiger costatus costatus* Dumitrica, Kozur et Mostler, *S.* sp. cf. *S. latus* Kozur et Mostler, *Spongopallium* sp. aff. *S. koppi* (Lahm), and *Triassobipedis* sp. These species are known from the Middle Triassic deposits of the Alpine–Mediterranean region (Kozur and Mostler, 1981, 1994; Lahm, 1984; Gorican and Buser, 1990) and Japan (Yao, 1990). Many of them, except for representatives of genera *Pseudostylosphaera* and *Spongopallium*, occur also in the Middle Triassic of New Zealand (Aita, 1994), which was considered, in accordance with the radiolarian distribution patterns, as an area of the Notal paleobiogeographic realm (Bragin, 1994). To all appearances, the species listed were cosmopolitan organisms. This opens a new biostratigraphic perspective for a direct correlation of boreal and tropical Triassic successions on the basis of radiolarians.

The problem of correlation between the boreal Triassic stratigraphy in northeastern Asia and the standard stratigraphic scale is well known to stem from a high biogeographic differentiation in the Middle–Late Triassic time. The boreal Triassic assemblages of mollusks considerably differ in their species composition from the tropical ones. Scarce cosmopolitan species of ammonoids have very wide stratigraphic ranges and are of no correlation value. The commonly used in biostratigraphic investigations are data on boreal and tropical ammonoid forms coexisting in some sections of British Columbia (Dagys *et al.*, 1979).

The lower part of the upper Ladinian deposits yielded several species, which are known from the Mediterranean region and show narrow stratigraphic ranges (Kozur and Mostler, 1994). For example, *Silicarmiger costatus costatus* was found in the lower and middle parts of the lower Ladinian. Distribution interval of *Silicarmiger latus* ranges from the middle part of the lower Ladinian to the upper Ladinian inclusive. *Parentactinia pygnax* is confined to the upper Anisian–lower Ladinian, while *P. inerme*, is typical of the lower Ladinian, and *Spongopallium koppi* is known from the lower Ladinian deposits. All these data permit a reliable correlation of Beds 9–11 of the Dzhugadzhak section with the lower Ladinian deposits of the Mediterranean region. This is very important because the same beds were attributed to the upper Ladinian based on assemblages of macrofauna (Dagys *et al.*, 1991; Dagys and Konstantinov, 1995).

The mentioned difference in the age determinations based on macrofauna and radiolarians needs to be explained. Two possible interpretations can be suggested:

(1) Radiolarian species had different existence periods in tropical and boreal areas. For instance, *Parentactinia pygnax, Silicarmiger costatus*, and some other species, which became extinct in the tropical region by the end of the early Ladinian, continued to exist in the Boreal and Notal areas.

(2) The macrofauna-based attribution of the boreal Ladinian deposits to the units of the standard scale is insufficiently precise.

The available materials are inappropriate for checking these interpretations. The problem can be solved after a thorough investigation of Triassic radiolarian distribution in other boreal sections (e.g., in Novosibirskie Islands, Brooks Ridge, Spitsbergen) and better understanding of Triassic stratigraphy in tropical regions. In addition, we should find and analyze radiolarians from transitional zones between tropical to boreal areas.

Species like *Glomeropyle boreale*, and early *Ferresium* (?), as well as spherical spongy forms, are untypical of the Middle Triassic deposits in the tropical belt. Probably, their range of geographic distribution was limited by the high latitudes. The genus *Glomeropyle* occurs in the Middle Triassic beds of both the Omolon massif and New Zealand (Aita, 1994). This genus likely had bipolar distribution areas that is not surprising, if we take into consideration a great amount of recent radiolarian taxa showing the same distribution pattern (Petrushevskaya, 1986). A series of species in common permits correlation between Triassic deposits of the Omolon massif and New Zealand, where the corresponding rocks are poorly characterized by macrofauna.

The uppermost Ladinian–lower Carnian radiolarian assemblages from the Dzhugadzhak section are of a low taxonomic diversity. They comprise only few spe-

cies (*Archaeocenosphaera* sp., *Pseudostylosphaera omolonica* sp. nov., and *Ferresium* (?) sp.) unknown from other regions, thus being useless for correlation. In this stratigraphic interval of the section, phosphorites and fine clastic deposits become gradually less widespread. No radiolarians have been found at the higher level of the Carnian Stage, where siltstones and sandstones finally replace mudstones and phosphorites disappear. This level in the study region may correspond to the sea regression at the early Late Triassic time.

CONCLUSION

Analyzing distribution of the Middle and Late Triassic radiolarians in the Dzhugadzhak section, we arrived at the following conclusions:

(1) The section contains three successive assemblages: that of the late Anisian with *Entactinia* and *Pseudostylosphaera* (?) sp. ex gr. *P. fragilis*, the late Ladinian *Glomeropyle boreale–Silicarmiger costatus costatus* assemblage, and the late Ladinian–early Carnian assemblage with *Pseudostylosphaera omolonica*. The facies-dependent taxonomic diversity of the assemblages increases at the stratigraphic levels rich in phosphorites and bituminous shales, which probably correspond to transgression episodes. The radiolarian assemblages identified can be used for local subdivision of the sections.

(2) The boreal Triassic radiolarian assemblages that are studied for the first time significantly differ in taxonomic composition from the coeval tropical assemblages. They lack characteristic tropical taxa of the families Muelleritortiidae and Oertlispongiidae including only few representatives of Triassocampidae. Accordingly, radiolarians can serve as paleoclimatic indicators for the Middle–Late Triassic period.

(3) The Ladinian radiolarian assemblages from the Omolon massif and New Zealand include a number of cosmopolitan species having narrow stratigraphic ranges. Using them, we can correlate the studied Triassic deposits with those of the Mediterranean region. This approach is particularly helpful for solving the fundamental problem of correlation between Triassic deposits accumulated in the high- and low-latitude zones.

PALEONTOLOGICAL DESCRIPTION

Genus *Pseudostylosphaera* Kozur et Mostler, 1981

Pseudostylosphaera omolonica sp. nov.

Plate IV, figs. 7–9.

The name is derived from the Omolon River in northeastern Siberia.

Holotype: GIN no. 7438-89-2, the Omolon massif, Dzhugadzhak River, Bed 14, specimen L-2 (0.3 m above the bed base); Upper Triassic, lower Carnian, the *Nathorstites tenuis* Zone.

Description. Large, spherical, slightly tubercular cortical shell of the two-layer structure. The outer layer is formed of big polygonal (predominantly pentagonal) porous frames with massive nodes at vertices, which appear as tubercles on the shell surface. Two main spines are moderately long (sometimes slightly longer than the cortical shell diameter), relatively thin, Y-shaped in cross section, having massive flattened ridges separated by narrow grooves extending nearly up to spine ends. Some specimens show indistinct right-spiral sculpturing of a spine.

Comparison. The species differs from *Pseudostylosphaera compacta* (Nakaseko et Nishimura, 1979) as having shorter spines and larger cortical shell. Poorly developed spiral sculpturing of thinner spines makes it distinct from *P. inaequata* (Bragin, 1986) and *P. goestlingensis* (Kozur et Mostler, 1981).

Material: 14 specimens from two samples of the Dzhugadzhak section (Sample 8-25 from the upper Ladinian and Sample L-2 from the lower Carnian levels).

Distribution: the Middle–Upper Triassic (upper Ladinian–lower Carnian) of the Omolon massif.

ACKNOWLEDGMENTS

The work is supported by the International Science Foundation (grant no. MR 6300) and the Russian Foundation for Basic Research (project nos. 97-05-65864 and 97-05-65566).

Reviewers A.S. Alekseev and V.S. Vishnevskaya

REFERENCES

Aita, Y., Abstracts of Papers, *INTERRAD VII*, Osaka, 1994.

Bragin, N.Yu., *Radiolyarii i nizhnemezozoiskie tolshchi Vostoka SSSR* (Radiolarians and Lower Paleozoic Sequences in the Eastern USSR), Moscow: Nauka, 1991.

Bragin, N.Yu., Radiolarians as Indicators of Triassic Climate in Northeastern Asia, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 1, pp. 81–85.

Bychkov, Yu.M., Kuznetsov, V.M., Zhulanova, I.L., and Byalobzheskii, S.G., Local Triassic Stratigraphic Units of the Kolyma–Omolon Region and the Northern Okhotsk Area, *Preprint of Sev.-Vost. Nauchn. Center Dal'nevost. Otd. Ross. Akad. Nauk*, Magadan, 1996.

Carter, E.S., Biochronology and Paleontology of Uppermost Triassic (Rhaetian) Radiolarians, Queen Charlotte Islands, British Columbia, Canada, *Mem. Geol.* (Lausanne), 1993, no. 11.

Dagys, A.S. and Konstantinov, A.G., New Zonation Scheme of the Ladinian Stage for Northeastern Asia, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 3, pp. 121–127.

Dagys, A.S., Arkhipov, Yu.V., and Bychkov, Yu.M., *Stratigrafiya triasovoi sistemy Severo-Vostoka Azii* (Triassic Stratigraphy of Northeastern Asia), Moscow: Nauka, 1979.

Dagys, A.S., Konstantinov, A.G., and Sobolev, E.S., Materials for the Boreal Ladinian Biostratigraphy, in *Biostratigrafiya i paleontologiya triasa Sibiri* (Triassic Biostratigra-

phy and Paleontology of Siberia), Novosibirsk: Nauka, 1991, pp. 74–95.

Dumitrica, P., Triassic Palaeoscenidiidae and Entactiniidae from the Vicentinian Alps (Italy) and Eastern Carpathians (Romania), *D.S. Inst. Geol. Geofiz.*, Bucharest, 1978, vol. 64, pp. 27–38.

Egorov, A.Yu., Bogomolov, Yu.A., Konstantinov, A.G., and Kurushin, N.I., Triassic Stratigraphy of the Kotel'nyi Island (Novosibirskie Islands), in *Boreal'nyi trias* (The Boreal Triassic), Moscow: Nauka, 1987, pp. 66–80.

Goduntsov, R.T., Simakov, K.V., and Shevchenko, V.M., Faunal Characterization of Triassic Deposits of the Southwestern Omolon Block, in *Mezozoiskie morskie fauny Sibiri i Dal'nego Vostoka SSSR i ikh stratigraficheskoe znachenie* (Mesozoic Marine Faunas of Siberia and the Far East of the USSR: Stratigraphic Significance), Moscow: Nauka, 1968, pp. 14–17.

Gorican, S. and Buser, S., Middle Triassic Radiolarians from Slovenia (Yugoslavia), *Geologija* (Ljubljana), 1990, vols. 31–32, pp. 133–197.

Kozur, H. and Mostler, H., Beitrage zur Erforschung der mesozoichen Radiolarien. Teil IV, *Geol. Paleont. Mitt. Innsbruck*, 1981, vol. 1.

Kozur, H. and Mostler, H., Anisian to Middle Carnian Radiolarian Zonation and Description of Some Stratigraphically Important Radiolarians, *Geol. Paleont. Mitt. Innsbruck*, 1994, vol. 3, pp. 39–255.

Lahm, B., Spumellarienfaunen (Radiolaria) aus dem mitteltriassischen Buchensteiner Schichten von Recoaro (Norditalien) und den obertriassischen Reiflingerkalken von Grossreifling (Osterreich). Systematik. Stratigraphie, *Munchner Geowiss., Abh. Reihe A: Geol. Paleontol.*, 1984, vol. 1.

Petrushevskaya, M.G., *Radiolyarievyi analiz* (The Radiolarian Analysis), Leningrad: Nauka, 1986.

Sashida, K., Lower Triassic Radiolaria from the Kanto Mountains, Central Japan. Part 1: Paleoscendidiidae, *Trans. Proc. Paleontol. Soc. Jpn., New Ser.*, 1983, no. 131, pp. 168–176.

Sugiyama, K., Lower and Middle Triassic Radiolarians from Mt. Kinkazan, Gifu Prefecture, Central Japan, *Trans. Proc. Paleontol. Soc. Jpn., New Ser.*, 1992, no. 167, pp. 1180–1223.

Yao, A., Triassic and Jurassic Radiolarians, in *Pre-Cretaceous Terranes of Japan*, 1990, pp. 329–345.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 372–377. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 59–64.
Original Russian Text Copyright © 2000 by Il'ina.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

On the Regional Konkian Stage (Middle Miocene) in the Eastern Paratethys

L. B. Il'ina

Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow, 117647 Russia

Received May 15, 1998

Abstract—The paper summarizes paleontological and stratigraphic data on the regional Konkian Stage in the Northern Black Sea, Crimea–Caucasus, and Transcaspian regions. Based on original and published materials, it is shown that the Mediterranean polyhaline elements occur at different stratigraphic levels indicating that the repeated expansion of the Konkian sea was accompanied by the increasing water exchange with the Mediterranean Sea and prochoresis of the marine fauna. At least three prochoresis events are registered for the Konkian time: at the initial ("Sartagan"), middle, and terminal ("Veselyanka") stages of the age. Owing to misunderstanding in dating these levels, it is proposed to deny the previously accepted subdivisions of this regional stage until the Konkian stratigraphy is clarified. In addition, the term "Sartagan" should be rejected because the Sartagan section lacks the basal Konkian layers with polyhaline fauna. Following E.M. Zhgenti, the Kartvelian is proposed to be considered as a unit of the regional stage rank.

Key words: *regional Konkian Stage, Kartvelian, Sartagan, Veselyanka, Eastern Paratethys, polyhaline mollusks, prochoresis.*

Despite the fact that Konkian deposits were under study for almost a century, the range of the regional Konkian Stage and its stratigraphy still remain debatable.

First of all, unsolved is the age problem of the Pholadidae or Kartvelian (Davitashvili, 1930) Beds. Andrusov (1917), who was first to establish the regional Konkian Stage (horizon), considered it as a facies analogue of fossiliferous marine Konkian deposits. Even then, when it was shown that the Pholadidae Beds occur under the Konkian strata proper (Osipov, 1927), most researchers continued to include them into the regional Konkian Stage (Merklin, 1953; Pavlinova-Il'ina, 1957; Krasheninnikov, 1959; Eberzin, 1960; Molyavko, 1960; Bidzinashvili, 1967, 1974; Barg, 1969, 1993; and others). Other geologists refer the Kartvelian Beds in their complete range to the regional Karaganian Stage (Bogdanovich, 1965; Buryak, 1965; Nosovskii, 1971, Koyumdzhieva and Popov, 1985; and others). Precisely this subdivision scheme is recommended in the volume "Straigraphy of the USSR. Neogene System" issued in 1986.

Zhizhchenko (1959) also believed that the Pholadidae Beds should be referred to the regional Karaganian Stage, however, he noted that they can be sometimes of the Konkian age and proposed the term "Kartvelian Beds" to be used for the Pholadidae Beds of the Karaganian age only. Based on the evolutionary development of pholads, Zhgenti (1976, 1981, 1991, and others), who never united the Kartvelian and Karaganian and considered, in her early papers, the Pholadidae Beds as representing the lower member of the Konkian Horizon, proposed to consider the Kartvelian as an autonomous regional stage (initially, horizon). In this paper, I follow this standpoint. Dzhanelidze (1970) also supported an autonomous status of the Kartvelian.

Sediments of the regional Konkian Stage are known in area stretching from the eastern Ust'urt Plateau in the east to southeastern areas of the Nikolaev district of Ukraine and further to the interfluve area of the Dniester and Prut rivers in the west, where they are recovered by boreholes (Roshka *et al.*, 1968). Their westernmost exposures are registered in northeastern Bulgaria (Strashimirov, 1961). In the north, these deposits occur at the latitude of Nikopol' and the Konka River basin. Along the deep river valleys (for instance, along the Don River paleovalley), the Konkian sea penetrated significantly farther to the north. The southernmost outcrops of the Konkian deposits are known in the Talysh area of Azerbaijan, in the southern part of the Kopet-Dag, and at the Mt. Sirim in Turkmenistan.

Andrusov (1917) considered beds yielding *Venus konkensis* and described by Sokolov (1899) in the vicinity of the Veselyanka Settlement, near the joint area of the Skotovataya Ravine and Konka River (Zaporozh'e district, Ukraine), as representing the stratotype section of the regional Konkian Stage. In this site, Konkian strata "rest upon coastal continental sandy deposits of the Miocene, the exact age of which is unclear, and are separated from overlying coquina–sandy rocks of the lower Sarmatian by a bed of greenish

microporous clay considered by Sokolov (1899) as a marker of stratigraphic unconformity between the *Venus konkensis* Beds and lower Sarmatian" (Nosovskii, 1971, pp.13–14).

The lower part of the stratotype about 2 m thick contains shells of mollusks *Parvivenus konkensis* (Sok.), *Loripes dentatus* Defr., *Mactra basteroti konkensis* Sok., *Anomia ephippium* L., *Corbula michalskii* Sok., *C. gibba* Ol., *Donax intermedius* M. Hoern., *Ervilia pusilla trigonula* Sok., *Venerupis vitaliana* (Orb.), *Plicatiforma praeplicata* (Hilb.), *Sandbergeria perpusilla* (Grat.), single *Bittium spina* (Partsch.), *Hadriania boekhi* (R. Hoern. et Annig.), *Ringicula auriculata paulucciae* Morel., and some others. Foraminifers are represented here by small *Elphidium macellum* (F. et M.) and *Streblus beccarii* (L.). Higher in the section, dark green sands contain abundant shells of *Parvivenus konkensis, Ervilia pusilla trigonula, Acanthocardia andrussovi* (Sok.), and *Sandbergeria perpusilla.* The composition of the foraminiferal assemblage remains unchanged.

The stratotype section corresponds only to the upper part of the regional Konkian Stage. Most complete sections of the stage are located mainly in the Transcaspian region and Transcaucasia, where the unit is divided into the lower (Sartagan) and upper (Veselyanka) substages (*Stratigrafiya SSSR*, 1986).

Following Zhizhchenko (1937), the term "Sartagan" was applied to the basal Konkian layers overlying the Kartvelian and containing sufficiently rich assemblage of polyhaline mollusks, foraminifers, nannoplankton, rare radiolarians, echinoderm remnants, corals, and other fossils. Mollusks are usually represented here by species of *Glycymeris, Arca, Barbatia, Anadara, Atrina, Chlamys, Callista, Europicardium, Linga, Divalinga, Glans, Cardites, Dosinia, Diloma, Natica, Spiratella*, and some other genera. In eastern Georgia, there are present even rare representatives of polyhaline marine families Strombidae, Conidae, and Cypraeidae (Zhgenti, 1981, 1991). Foraminifers correspond to buliminids, peneroplids, particular miliolids, elphidiids, nonionids, bolivinids, rare polymorphinids, lagenids, and globigerinids typical of the basins with normal salinity. Also encountered are species of polyhaline and thermophilic Alveolinidae: *Borelis melo* (F. et M.) and *B. haueri* (Orb.) (Grachevskii, 1954; Krasheninnikov, 1959; Dzhanelidze, 1970). Ostracods occurring in these deposits (*Cytherella muelleri* (Muenst.) and others) also characterize the normal salinity in their habitat basin (Shneider, 1959).

It should be noted that the paleontological content of the so-called Sartagan beds in the type area (the Sartagan Ravine in Mangyshlak), as it is described by Andrusov (1917), does not correspond to the characteristics given above. They lack here polyhaline fossil assemblages, and their fauna resembles that from the stratotype of the regional Konkian Stage in the Konka River basin. This fauna demonstrates correctness of the opinion of Eberzin (1960, p. 243), who concluded that the Sartagan Ravine section corresponds to "the upper subhorizon of the stage (Konkian–*L.I.*), where stenohaline, though less diverse elements still exist." Consequently, the term "Sartagan Beds," when applied to the lower part of the regional Konkian Stage with the polyhaline fauna, is misleading and should be replaced with a new one. Nonetheless, one should be very careful in this case, because the basal part of the Konkian sequence is eroded in many areas and the upper Konkian deposits enriched in polyhaline elements and termed by Merklin (1953) as the Veselyanka Beds, are frequently taken for the so-called Sartagan unit.

The Veselyanka Beds are generally characterized by the less diverse marine fauna dominated by endemic species and subspecies. However, some Konkian sections, the Veselyanka Beds included, contain polyhaline fauna at some levels. This fact was noted by Eberzin (1960) in the Transcaspian region and by Bidzinashvili (1967, 1974) in the Transcaucasia, apparently being characteristic of the entire Eastern Paratethys (Il'ina, 1993; Goncharova and Il'ina, 1997). When studying some borehole sections in southern areas of Ukraine, Barg (1993) defined the following polyhaline molluscan species in the Veselyanka assemblage: *Dosinia exoleta* (L.), *Glycymeris pilosa* (L.)., *Chlamys* ex gr. *malvinae* (Dub.), *Turritella* cf. *spirata* (Brocc.), *Natica millepunctata* Lam., and others, which can point, in her opinion, to the water exchange between the Borisfen Bay and Central European basins with normal salinity.

Although the difference between faunal assemblages from the so-called Sartagan Substage corresponding to the basal deposits of the Konkian section and from bed (or beds) yielding fairly polyhaline elements within the Veselyanka interval is perceptible, precisely this "Veselyanka" level can be taken, however, and appears to be usually taken for the so-called Sartagan, if the basal layer of the regional Konkian Stage is missing. It is not an occasional statement that "beds with *Venus konkensis* rest upon the Pholadidae Beds (Nosovskii, 1971; Barg, 1993).

The difference between assemblages from the basal Konkian ("Sartagan") layers and from higher Veselyanka horizons consists in the following. While the assemblage of the former includes mainly polyhaline species, the polyhaline assemblage of the latter is a companion of more abundant euryhaline species and Konkian endemics, such as *Parvivenus konkensis, Mactra basteroti konkensis* Sok., *Acanthocardia andrussovi* (Sok.). and others. The Veselyanka deposits frequently enclose small accumulations of relatively polyhaline turritellids, which are very rare, for unknown reasons, in the Sartagan layers, but characteristic of younger sediments.

The Transcaspian region, or to be more exact, the northwestern Turkmenistan, is one of several regions, where one section can show several levels (basal and

inside the Veselyanka interval) that yield polyhaline fauna. For instance, in the Dakhly and Goklenkuyusy well areas to the south of the Aginysh descent in the Kumsebshen depression, where the Konkian deposits are fairly widespread, Eberzin detected two such levels. The lower of them ("Sartagan") that overlies the Kartvelian strata is characterized by polyhaline relatively large bivalves: *Anadara turonica* (Duj.), *Barbatia barbata* (L.), *Glycymeris pilosa, Linga columbella* (Lam.), *Saxolucina incrassata* (Dub.), *Glans trapezia* L., *G. rudista* (Lam.), *Callista italica* (Defr.), *Acanthocardia paucicostata* (Sow.), and *Europicardium multicostatum* (Brocc.), which associate with species of the *Chlamys, Venus, Dosinia, Circe*, and many other genera (Eberzin, 1960; Merklin and Nevesskaya, 1955; *Opredelitel' miotsenovykh* ..., 1993), and also with gastropods *Diloma orientalis* (Cossm. et Peyr.), *Gibbula buchi* (Dub.) *Natica millepunctata, Nassarius dujardini* (Desh.), *N. zborzewskii* Andrz., and with shells of the *Cantharus, Mitrella, Murex*, and other genera (Il'ina, 1993). *Turritella* specimens are occasional in this assemblage.

This level of polyhaline fauna corresponds to gypsum-bearing coquina and marly limestone beds 0.5 to 2.0 m thick in total (Eberzin, 1960). The beds are overlain by the sequence (3.0 to 36.0 m thick in total) of marls and limestones with interbeds of coquina limestone and gypsum. The sequence yields shells of *Parvivenus konkensis, Loripes dentatus, Plicatiforma praeplicata*, rare *Mactra basteroti konkensis, Acanthocardia andrussovi, Gibbula, Mohrensternia, Potamides*, and others, i.e., an assemblage typical of the upper (Veselyanka) part of the regional Konkian Stage. About 4.3–5.5 m above the basal (Sartagan) layer, the sequence hosts the second level with polyhaline mollusks *Anadara turonica, Linga columbella*, large smooth-shelled bivalves, and ceritids (Eberzin, 1960) (Fig. 1a).

Polyhaline mollusks were also observed inside the Veselyanka interval of some sections in the western Ciscaucasia (Pavlinova-Il'ina, 1957). In the Chumnaya Ravine near the Tul'skii Settlement in the Belaya River basin (Fig. 1b), the Kartvelian sands and sandstones with *Barnea ustjurtensis* (Eichw.), *B. pseudoustjurtensis* Bog., and rare *Ervilia pusilla trigonula* are overlain by a gray siltstone layer (1.5 m), whose upper part yields *Mactra* sp. The layer grades upward into the sequence of brown and yellowish brown sands and sandstones with abundant *Mactra* cf. *basteroti konkensis* (10.0 m). Approximately 5 m above the base of the sequence, there are coquina layers (to 15 cm) with abundant and diverse mollusks: *Mactra basteroti konkensis, Parvivenus konkensis, Aveinus nitidus* (Reuss), *Loripes dentatus, Mytilaster volhynicus kolesnikovi* (Liver.), *Acanthocardia andrussovi, Corbula gibba, Modiolus hoernesi* Reuss, *Chlamys diaphana* (Dub.), *Ch. pusio* (L.), *Parvivenus marginata* (M. Hoern.), *Chama gryphoides* Lam., *Onoba laevigata* (Eichw.), *Mitrella scripta* (L.), *Natica millepunctata*, and others. By its position in the section, this level with polyhaline mollusks corresponds to the same level in the Transcaspian sections.

The Konkian sands and sandstones of the Chumnaya Ravine section are overlain by siltstones and then by sands with the early Sarmatian fauna (cardiids, mactriids, large tapetins, and others). The base of the sandy member is marked by a layer with the Sarmatian fauna displaying a high abundance of trochids (*Gibbula*) and single damaged to rounded shells of undoubtedly redeposited *Turritella pythagoraica* Hilb. and *Natica millepunctata*. The similar Konkian section is also exposed in the neighboring Vertepka Ravine.

The occurrence of polyhaline fauna (mollusks, foraminifers, nannoplankton, and others) at different levels of the regional Konkian Stage is also registered in other regions (Transcaucasia, central Ciscaucasia, northern Black Sea region). This fact cannot be explained either by redeposition (Merklin, 1953) or survival (Bidzinashvili, 1974) of Sartagan polyhaline taxa in the later period of the Konkian time. The phenomenon is undoubtedly related to repeatedly increasing water exchange of the Konkian basin with open seas and to prochoresis of the marine fauna during ingressions of the Mediterranean Sea into the Eastern Paratethys.

At least two events of prochoresis can be noted. The first of them is clearly recorded in the Transcaspian (Eberzin, 1960) and western Black Sea regions (Pavlinova-Il'ina, 1957; and others), and also in some areas of the northern Black Sea region (Barg, 1993; and others). The later prochoresis corresponding to the very end of the Konkian Age, prior to the early Sarmatian transgression event, is recorded in some Georgian sections (Nasperi, Vardziya, Kvaliti localities, and peripheral areas of the Dzirul massif). In the section near the Nasperi Settlement (Fig. 1c), the Kartvelian clay and siltstone beds with *Barnea* are overlain by the siltstone and sandstone sequence with marine mollusks *Corbula gibba, Clausinella basteroti* (Desh.), *Venus cincta, Aporrhais alatus* (Eichw.), and others attributed by Bidzinashvili (1974) to the Sartagan level. The thickness is 11.2 m. The sequence is in turn overlain by alternating sandstone and siltstone strata with typical Veselyanka mollusks: *Mactra basteroti konkensis, Ervilia pusilla trigonula, Paphia, Donax*, and others. The strata are about 45 m thick. The Nasperi section is crowned by the 5-m-thick sandstone layer yielding *Obsoletiforma lithopodolica ruthenica, Mactra basteroti konkensis*, and *Venerupis vitaliana*, all characteristic of the topmost Veselyanka interval. These species occur, however, in association with rare polyhaline and relatively polyhaline *Chlamys malvinae, Turritella pythagoraica, Corbula gibba, Natica millepunctata, Nassarius* cf. *dujardini*, and some other molluscan species typical of the Sartagan level. "In its stratigraphic position, this layer is transitional between the Konkian and Sarmatian." (Bidzinashvili, 1974, p. 83).

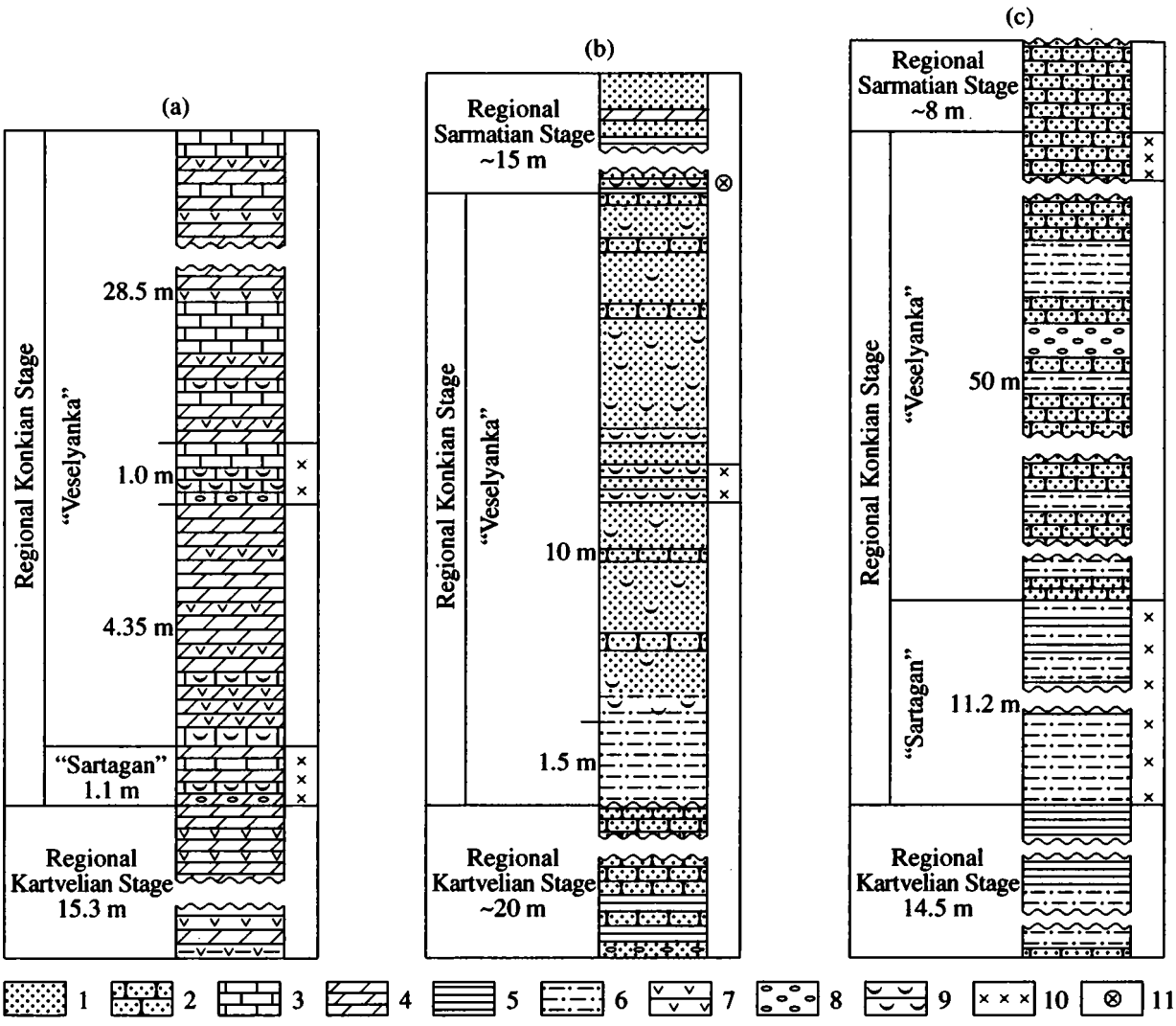


Fig. 1. Konkian sections in (a) the Kumsebshen depression north of the Dakhly descent, northwestern Turkmenistan (after Eberzin, 1960), (b) Chumnaya Ravine near the Tul'skii Settlement, Belaya River basin, western Ciscaucasia, and (c) near the Nasperi Village, western Georgia (after Bidzinashvili, 1974): (1) sand; (2) sandstone; (3) limestone; (4) marl; (5) clay; (6) silt, siltstone; (7) gypsum; (8) pebblestone, conglomerate; (9) coquina; (10) occurrence levels of polyhaline faunas; (11) redeposited shells of polyhaline species.

In some sections of the interfluve area between the Khuru and Ochkhamuri rivers, the uppermost layers of the Konkian Stage are marked by a distinct preponderance of *Helicosphaera kamptneri* Hay et Mohler amid the algal flora. In opinion of Minashvili (1986), this is an indication of the normal marine regime at that time, and she proposed to term this stratigraphic level as the *Helicosphaera kamptneri* Beds.

In addition to sections in Georgia, the late prochoresis (at the very end of the Veselyanka time) can also be recognized in the Transcaspian region (the Uzen' depression, data of S.O. Khondkarean; the northern Kara-Bogaz area, data of L.A. Nevesskaya), in the lower course of the Don River (Novocherkassk, data of Bogachev, 1901, 1905), near the Sea of Azov (the Sukhoi Nesvetai Ravine, Krepkaya River, data by Zinov'ev, 1957), and in the northern Black Sea and Ciscaucasia regions (Mt. Dubrovaya, data of Liverovskaya, 1935). This was a shirt-time excursion of marine fauna, when molluscan assemblages in the Eastern Paratethys were already reorganized and included those species, which later, during the early Sarmatian, became preponderant.

Redeposition of some polyhaline forms could take place in some areas, e.g., at the Mt. Dubrovaya locality, during the early Sarmatian transgression. However, they could be redeposited only from the uppermost Konkian deposits occurring in this area, but not from the Sartagan layers, as we should take into consideration the almost complete absence of the latter in the northern areas of the Eastern Paratethys. Undoubtedly redeposited from the uppermost Veselyanka sediments

are rounded shells of *Turritella pythagoraica* Holb. and naticids occurring in basal Sarmatian strata near the Tul'skii Settlement (Pavlinova-Il'ina, 1957).

Thus, at least three events of polyhaline fauna prochoresis occurred during the Konkian Stage: in its initial, middle and terminal periods. Because of the fragmentary distribution of sediments corresponding to these levels, their correct dating and reliable stratification of the Konkian sections represent a difficult problem. The term Sartagan cannot be applied to beds with polyhaline fossils at the base of the Konkian sequence, because these beds are missing from the stratotype of the regional Konkian Stage. Therefore, it is hardly reasonable to define now autonomous units with proper names within the regional Konkian Stage.

In this paper, I left aside the problem of locating a strait or straits, via which the prochoresis of the Mediterranean fauna into the Konkian basin could occur. This problem is specially discussed in several works (Sudo, 1961; Il'ina, 1993, 1995; and others). The main passage for water exchange with the open sea was in the southern part of the Konkian basin; at the end of the stage, the basin under discussion was probably connected also with the Western (Central) Paratethys (Didkovskii and Nosovskii, 1975; Goncharova and Il'ina, 1997).

On the basis of molluscan, foraminiferal, and nannoplankton assemblages, the regional Konkian Stage is correlative with the upper part of the Badenian Stage (Kosovian Substage) of the Western (Central) Paratethys (Andreeva-Grigorovich and Nosovskii, 1976). In the Mediterranean region, it corresponds partly to the Serravalian regional stage spanning the undifferentiated *Discoaster exilis* (NN6)–*Discoaster kugleri* (NN7) nannoplankton zones.

ACKNOWLEDGMENTS

The work was supported by the Russian Foundation for Basic Research (project 97-04-49870).

Reviewers V.A. Krasheninnikov and Yu.B. Gladenkov

REFERENCES

Andreeva-Grigorovich, A.S. and Nosovskii, M.F., Stratigraphic Analogues of the Konkian Stage in the Central Paratethys, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Cenozoic Stratigraphy of the Northern Black Sea Area and the Crimea), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1976, pp. 72–77.

Andrusov, N.I., The Konkian Horizon (Pholadidae Beds), *Tr. Geol. Mineral. Muz. Akad. Nauk*, 1917, vol. 2, no. 6, pp. 167–261.

Barg, I.M., Middle Miocene *Ervilia* and Pholadidae Assemblages of the Southern Ukraine, *Byull. Mosk. O-va Ispyt. Prir. Otd. Geol.*, 1969, no. 4, pp. 78–83.

Barg, I.M., *Biostratigrafiya verkhnego kainozoya Yuzhnoi Ukrainy* (Upper Cenozoic Biostratigraphy of the Southern Ukraine), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1993.

Bidzinashvili, L.M., About the Konkian Horizon in the Northern Piedmonts of the Imeretinskii Ridge, in *Materialy po geologii i neftegazonosnosti. Gruzii* (Materials on Geology and Oil and Gas Deposits of Georgia), Leningrad: Nedra, 1967, pp. 22–27.

Bidzinashvili, L.M., On the Upper Horizons of the Middle Miocene of Georgia, *Materialy po geologii i neftegazonosnosti Gruzii* (Materials on Geology and Oil-and-Gas Deposits of Georgia), Tbilisi: Metsniereba, 1974, pp. 70–95.

Bogachev, V.V., Signs of the Second Mediterranean Stage near Novocherkassk, *Izv. Geol. Kom.*, 1901, vol. 20, no. 36, pp. 219–232.

Bogachev, V.V., Molluscan Species Newly Found in the Miocene Deposits near Novocherkassk, *Izv. Geol. Kom.*, 1905, vol. 24, no. 5, pp. 159–188.

Bogdanovich, A.K., Stratigraphic and Facies-Dependent Distribution of Miocene Foraminifers in the Western Ciscaucasia: Implications for Their Genesis, *Tr. Krasnodar Fil. Vses. Nauchn.-Issled. Inst. Nefti*, 1965, no. 16, pp. 300–350.

Buryak, V.N., On Stratigraphic Subdivision of the Neogene in Western Ciscaucasia, *Tr. Krasnodar Fil. Vses. Nauchn.-Issled. Inst. Nefti*, 1965, no. 16, pp. 351–381.

Davitashvili, L.Sh., On the Konkian Horizon, *Az. Neft. Khozyaistvo*, 1930, no. 10, pp. 55–57.

Didkovskii, V.Ya. and Nosovskii, M.F., The Black Sea Depression: The Miocene, in *Stratigrafiya URSR, T. 10: Neogen* (Stratigraphy of the UkrSSR, vol. 10: The Neogene), Kiev: Naukova Dumka, 1975, pp. 32–70.

Dzhanelidze, O.I., *Foraminifery nizhnego i srednego miotsena Gruzii* (Early and Middle Miocene Foraminifers of Georgia), Tbilisi: Metsniereba, 1970.

Eberzin, A.G., The Neogene of Northern Turkmenistan, *Tr. Kompl. Yuzhn. Geol. Ekspeditsii Akad. Nauk SSSR*, 1960, no. 5, pp. 155–259.

Goncharova, I.A. and Il'ina, L.B., Relations between Middle Miocene Basins of the Western and Eastern Paratethys, *Stratigr. Geol. Korrelyatsiya*, 1997, vol. 5, no. 6, pp. 64–72.

Grachevskii, M.M., Evolution of the Konkian Fauna in Eastern Georgia, *Tr. Sekt. Paleobiol. Akad. Nauk GruzSSR*, 1954, vol. 2, pp. 89–135.

Il'ina, L.B., *Opredelitel morskikh srednemiotsenovykh gastropod Yugo-Zapadnoi Evrazii* (Guide Book to Middle Miocene Marine Gastropods of Southwestern Eurasia), Moscow: Nauka, 1993.

Il'ina, L.B., Connections of Middle Miocene (Tarkhanian–Konkian) Basins of the Eastern Paratethys with Surrounding Seas, *Ekosistemnye perestroiki i evolyutsiya biosfery* (Changes in Ecosystems and Biosphere Evolution), Moscow: Paleontol. Inst. Ross. Akad. Nauk, 1995, no. 2, pp. 133–136.

Koyumdzhieva, E. and Popov, N., Range and Subdivisions of the Karaganian Stage (Middle Miocene) in the Eastern Paratethys, *Geol. Balcanica*, 1985, vol. 15, no. 1, pp. 75–82.

Krasheninnikov, V.A., Foraminifers, in *Atlas srednemiotsenovoi fauny Severnogo Kavkaza i Kryma* (Atlas of the Middle Miocene Fauna of the Northern Caucasus and Crimea), Moscow: Gostoptekhizdat, 1959, pp. 15–103.

Liverovskaya, E.V., *Fauna konkskogo gorizonta gory Dubrovoi (Severnyi Kavkaz)* (Fauna of the Konkian Horizon, the Mt. Dubrovaya Site, Northern Caucasus), Leningrad, 1935.

Merklin, R.L., Miocene Evolutionary Stages of the Konkian Basin in the Southern UkrSSR, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1953, vol. 28, no. 3, pp. 89–91.

Merklin, R.L. and Nevesskaya, L.A., *Opredelitel' dvustvorchatykh mollyuskov miotsena Turkmenii i zapadnogo Kazakhstana* (Guide Book to Miocene Bivalves of Turkmenistan and Western Kazakhstan), Moscow: Akad. Nauk SSSR, 1955.

Minashvili, Ts.D., Miocene Biostratigraphy of Western Georgia Based on Calcareous Nannoplankton, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Tbilisi, Geol. Inst., Akad. Nauk GruzSSR, 1986.

Molyavko, G.I., *Neogen pivdnya Ukrainiyu* (The Neogene of the Southern Ukraine), Kiev: Akad. Nauk UkrSSR, 1960.

Nosovskii, M.F., Middle Miocene Biostratigraphy of the Northern Euxinian Basin, Southern Ukraine, in *Geologiya i rudonosnost' yuga Ukrainy* (Geology and Ore Deposits of Southern Ukraine), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1971, pp. 3–18.

Opredelitel miotsenovykh dvustvorchatykh mollyuskov Yugo-Zapadnoi Evrazii (Guide Book to Middle Miocene Bivalve Mollusks of Southwestern Eurasia), Moscow: Nauka, 1993.

Osipov, S.S., The Konkian Horizon of the Northern Caucasus and Kerch Peninsula, *Byull. Mosk. O-va Ispyt. Prir.*, 1927, vol. 5, nos. 3–4, pp. 351–376.

Pavlinova-Il'ina, L.B., New Data on the Konkian Fauna, in *Voprosy stratigrafii, fatsii i fauny paleozoya i kainozoya Severnogo Kavkaza* (Problems of Paleozoic and Cenozoic Stratigraphy: Facies and Fauna of the Northern Caucasus), Moscow: Gostoptekhizdat, 1957, pp. 138–159.

Roshka, V.Kh. and Khubka, A.N., Review of the Neogene Stratigraphy of the Dniester–Prut Interfluve, in *Biostratigrafiya antropogena i neogena yugo-zapada SSSR* (Anthropogene–Neogene Stratigraphy of the Southwestern USSR), Chisinau: Shtiintsa, 1981, pp. 78–106.

Roshka, V.Kh., Sinegub, V.V., Bobrinskaya, O.G., *et al.*, Middle Miocene Deposits of the Southern Prut–Dniester Interfluve, *Izv. Akad. Nauk MSSR, Ser. Biol. Khim. Nauk*, 1968, no. 3, pp. 50–56.

Shneider, G.F., Ostracods, in *Atlas srednemiotsenovoi fauny Severnogo Kavkaza i Kryma* (Atlas of the Middle Miocene Fauna of the Northern Caucasus and Crimea), Moscow: Gostoptekhizdat, 1959, pp. 107–140.

Sokolov, N.A., Beds with *Venus konkensis* at the Konka River, *Tr. Geol. Kom.*, 1899, vol. 9, no. 5.

Strashimirov, B., New Data on Middle Miocene Deposits to the South of the Town of Bugas, *God. Minno-Geol. Inst.*, 1961, vol. 7, no. 2, pp. 37–48.

Stratigrafiya SSSR. Neogenovaya sistema (Stratigraphy of the USSR. The Neogene), Moscow: Nedra, 1986, vol. 1.

Sudo, M.M., Immigration Directions of the Konkian Stenohaline Fauna, *Izv. Akad. Nauk TurkmSSR, Ser. Fiz.-Tekh., Khim. Geol. Nauk*, 1961, p. 123.

Zhgenti, E.M., *Lyutetsiidy srednego miotsena, ikh evolyutsiya i stratigraficheskoe znachenie* (Middle Miocene Luteciids: Their Evolution and Stratigraphic Significance), Tbilisi: Metsniereba, 1976.

Zhgenti, E.M., *Evolyutsiya i stratigraficheskoe znachenie nekotorykh srednemiotsenovykh bryukhonogikh Gruzii* (Evolution and Stratigraphic Significance of Some Middle Miocene Gastropods from Georgia), Tbilisi: Metsniereba, 1981.

Zhgenti, E.M., *Evolyutsiya i stratigraficheskoe znachenie mollyuskovoi fauny konkskogo yarusa Gruzii* (Evolution and Stratigraphic Significance of the Konkian Molluscan Fauna from Georgia), Tbilisi: Metsniereba, 1991.

Zhizhchenko, B.P., Data on the Second Mediterranean Stage, *Tr. Geol. Sluzhby Groznefti*, 1937, no. 6, pp. 133–200.

Zhizhchenko, B.P., Stratigraphy, in *Atlas srednemiotsenovoi fauny Severnogo Kavkaza i Kryma* (Atlas of the Middle Miocene Fauna of the Northern Caucasus and Crimea), Moscow: Gostoptekhizdat, 1959, pp. 7–12.

Zinov'ev, M.S., New Data on Konkian Deposits in the Rostov Area, *Dokl. Akad. Nauk SSSR*, 1957, vol. 114, no. 1, pp. 172–175.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 378–395. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 65–83.
Original Russian Text Copyright © 2000 by Naidin, Ben'yamovskii.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Stage Subdivision of the Paleocene

D. P. Naidin* and V. N. Ben'yamovskii**

** Moscow State University, Vorob'evy gory, Moscow, 119899 Russia*

*** Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 109017 Russia*

Received March 11, 1998

Abstract—In the southwestern Crimean Mountains, the lower Paleocene deposits (from 40–45 to 80–85 m thick) are perfectly exposed and fully characterized by macro- and microfossils. Two parts of the sequence are sharply different in paleontological aspect: the Danian bryozoan and foraminiferal limestones contain *Crania* and *Echinocorys*, and the Montian organogenic–detrital and foraminiferal limestones bear peculiar molluscan fauna and *Echinanthus*. According to parametric observations in the southwestern Crimean Mountains and some other distribution areas of the lower Paleocene carbonate rocks, the thickness of the Danian deposits is of the same order, but slightly greater than that of the Montian rocks. Inadequacy of the traditional stratotypes of the Paleocene stages (indistinct contacts with underlying and overlying deposits, hiatuses, unclear biostratigraphy, and others) can be compensated to some degree by other reference sections of the European paleobiogeographic realm. Sections exposed at the Churyuksu (the Bakhchisarai section), Kacha, and Bel'bek rivers (the Bel'bek section) of the southwestern Crimean Mountains are proposed as supplementary for the reference section. The stratotype section for a vast geological region should be composed of several reference sections to make stratigraphic investigations most effective. Based on the historical–geological data, the Paleocene deposits are subdivided into the lower and upper subseries. The lower subseries comprises the Danian and Montian stages.

Key words: *Danian, Montian, stratotypes, additional reference sections of the southwestern Crimean Mountains, biostratigraphic characteristics, comparative analysis, validity of the Montian.*

This article continues the discussion on stage subdivision of the Paleocene, which was initiated ten years ago by publications in the journal regretfully little-known to Russian and, especially, to foreign biostratigraphers (Naidin and Ben'yamovskii, 1988, 1989). Main statements in these publications and some articles of Naidin (1960, 1964, 1972) are as follows.

(1) The Paleocene subdivision into stages compatible with the natural historical–geological development, but not into zones, should be of a main concern.

(2) Validity of the stages is determined by their "biostratigraphic essence", i.e., by assemblages of macro- and microfauna. Planktonic foraminifers found in the stratotype sections are especially significant in this case.

(3) Microplankton is of prime importance for stratigraphic correlations. In particular, the Montian Stage is accepted to correspond in range to the *Acarinina inconstans* Zone. Although the evolution of benthic foraminifers suggests the close relations between the Montian and upper Danian deposits, the former should not be interpreted as upper horizons of the Danian Stage. The commonly accepted correlation between the Montian Stage and higher foraminiferal zones of *Morozovella angulata* and *M. conicotruncata* (*Resolution...*, 1989) is insufficiently substantiated.

(4) To maintain stability of the stratigraphic basis, we should use the universally recognized stages of Western Europe representing the western part of the European paleobiogeographic realm (EPR).

(5) Stratotypes of the stages are characterized, to a variable extent, by particular shortcomings, like unsatisfactory state of exposures, facies variations, hiatuses, indistinct contacts with underlying and overlying deposits, and others. Accordingly, it is necessary to overcome the situation using supplementary sections of the European paleobiogeographic realm.

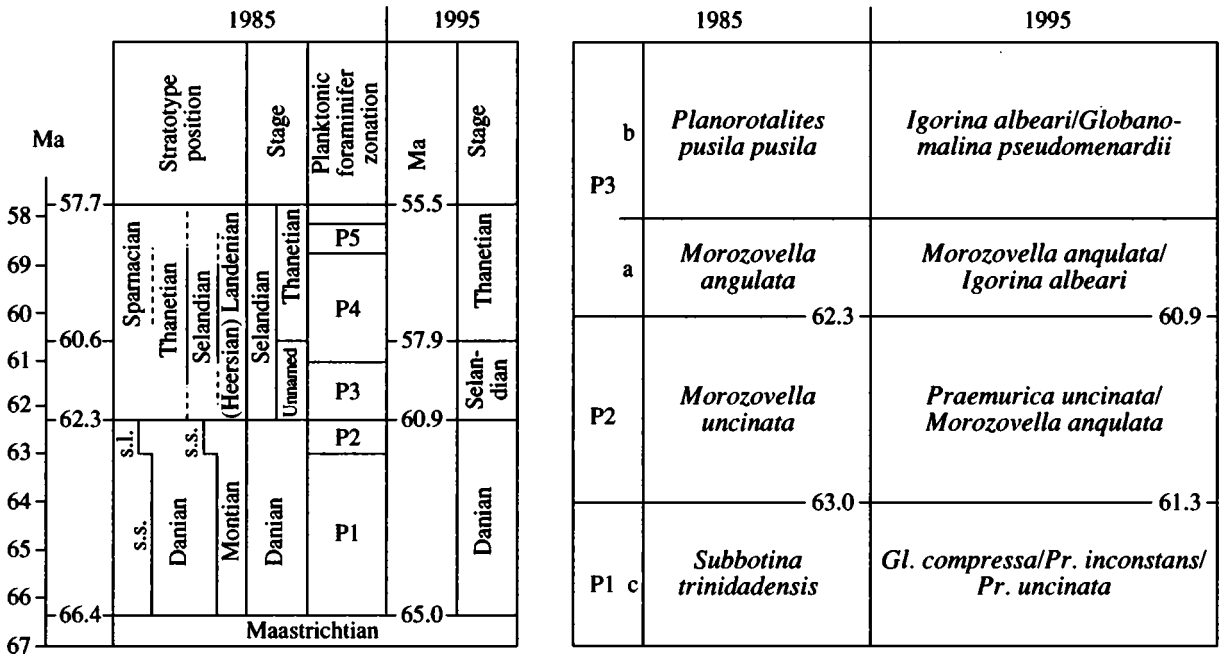
(6) Correlations should be based on widespread organic remains like microfossils and nannoplankton. The paleobiogeographic control should be decisive in establishing distribution ranges of all organic remains.

(7) Two subseries each divisible into two stages can be outlined in the paleobiogeographic evolution of the Paleocene seas in the European paleobiogeographic realm and adjacent Tethyan areas. Accordingly, the Paleocene Series (Epoch) is divided into the lower (early) part including the Danian and Montian stages (ages) and the upper (late) one spanning the Selandian and Thanetian stages (ages).

Some of the statements are supplemented and discussed in detail below.

The main emphasis is placed on the validity of the *Montian Stage* of the Paleocene. This stage, which was in worldwide usage not long ago, has been withdrawn from the "latest" stratigraphic schemes.

Table 1. Stage subdivision of the Paleocene according to Berggren *et al.*



According to the first statement, the stage is a natural historical–geological unit of stratigraphy. It is recognized by establishing the vertical range of its "principal assemblage of macrofauna" persistently traceable over a large paleoclimatic (paleobiogeographic) realm. For practical purposes of interregional correlation it is important that the deposits should contain abundant microfossils and nannoplankton remains.

BRIEF REVIEW OF THE PALEOCENE STAGE SUBDIVISION

A brief review of proposed variants of the Paleocene stage subdivisions is presented below.

The Paleocene was subdivided into the lower (Danian) and upper (Thanetian) stages by Cavelier and Pomerol (1986), Haq *et al.* (1987), and Bignot (1993).

The Danian, Montian and Thanetian stages envisaged in the schemes of Morozova (1960, and others), Gorbach (1972), Amitrov (1993), Pozaryska and Szczechura (1968), and Krach (1981) are adopted by the Interdepartmental Stratigraphic Committee (*Resolution...*, 1983, 1989). The same three stages were proposed by Makarenko (1961) and Panteleev (1974), who, however, included the Danian into the Upper Cretaceous. Salaj (1980) suggested to substitute the Thanetian by the Landenian, and Robaszynski (1979) considered this subdivision as corresponding to the lower Landenian together with the basal Heersian Stage. Some other stratigraphers also use the term "Landenian" instead of "Thanetian".

In the last 10–15 years, some authors use with great caution the term "Selandian" (Naidin and Ben'yamovskii, 1988, pp. 11–13). Moroz and Savron' (1975) were probably the first, at least, in the Russian publications, to subdivide the Paleocene into the Danian, Montian, Selandian and Thanetian stages. The Paleocene subdivision into three stages (Danian, Selandian, and Thanetian) is supported by Moorkens (1998), who placed, however, the interrogation mark at the level of the Danian–Selandian boundary.

The recognition of the Selandian was initiated by Berggren (1965). At first he subdivided the Paleocene into the Danian, Danian–Montian, and Landenian stages; the latter stage consisting of the Thanetian and Sparnacian substages. Later he proposed other variants of the Paleocene stage subdivision, which are shown in Table 1. The evolution of the Berggren's view on the Selandian as a unit of the Paleocene demonstrates the obstacles a stratigrapher meets when he attempts to clarify the post-Cretaceous stratigraphy elaborated during many decades by different researchers of Western Europe, where the standard Paleogene stage subdivision appeared.

Cavelier and Pomerol (1986, pp. 256, 260, Table 1) do not consider it possible to include the Selandian Stage into the international stratigraphic schemes because of its inadequate biostratigraphic substantiation and very disputable stratotype.

However, the Danian, Selandian and Thanetian stages were formally adopted by the 28th International Geological Congress in Washington as units of "the standard chronostratigraphic scale of the Paleocene" (Jenkins and Luterbacher, 1992). In this connection, Steurbaut (1998, pp. 143, 146) noted that, in accord with the priority principle and completeness degree of

Table 2. Belgian regional and local subdivisions of the Paleocene and Eocene

Series	Stage	Formation		
Eocene	Lutetian	Lede Brussels Aalter: Sand Complex		
		Oedelm Aalterbrugge		
	Ypresian	Vlierzele		
		Ieper		
		Northwest	North and Center	Southeast
			Merelbeke Clay	
			Egem Sand	Mont-Panisel Sand
			Clay: Kortmark	
		Flanders Clay	Aaalbeke	Mons-en-Pevele Sand
			Roubaix	Peissant Sand, Morlanvelz Clay
			Orchies	
Paleocene	Landenian "Heersian"	Landen		
		South (Montian Basin)		East and Northeast
		Sand: Erquelinnes, Granglise		Sand: Dormaal, Racour
		Tuffaceous Chalk of Angre-Chereq		Tuffaceous Chalk of Lincent
		Bertaimont		Heers: Gelinden Marl, Orp Sand
	Danian (= "Montian")	Hainin Limestone and Lignite Mons Limestone Cuesmes Limestone Tuffaceous Ciply Chalk Poudingue de la Malogne		Eisden Limestone and Lignite Mechelen-aan-de-Maas Limestone Tuffaceous Chalk of Vroenhoven

After Robaszyński (1979), Steurbaut (1988), and others.

stratotypes, the Selandian should be substituted by the Heersian, and the Thanetian by the Landenian .

The term "Danian" needs to be additionally explained. In some stratigraphic schemes, it denotes coeval interchangeable facies of the Danian and Montian deposits, whereas in the others, the Montian is an upper part of the Danian Stage. For the latter case, Mangin suggested the term "binome Danien–Montien" (Marliére, 1964, p. 884).

SHORTCOMINGS OF THE TRADITIONAL PALEOCENE STAGE STRATOTYPES

Historically established Paleogene stage stratotypes are those located in the areas absolutely inappropriate for the case. These are areas of discrete natural and mining exposures (quarries, mines, and wells), which exhibit separate intervals of the succession composed of different facies.

One of these areas is the Belgium territory. Table 2 seems to clearly demonstrate the difficulties in correlation and choice of the reference standards, i.e., of stratotypes.

The most significant disadvantage of Western Europe for choosing the Paleogene stage stratotypes is that the post-Danian extensive regression in response to the global eustatic sea-level fall is most distinctly recorded in the local rock sequences (Haq *et al.*, 1987). This event corresponds to a large hiatus in the schemes of Aubry (1985, Fig. 2) and Pomerol (1989, Table 2). Nevertheless, the Paleocene stage stratotypes of Western Europe were used to substantiate questionable stratigraphic schemes. For instance, Bignot (1993, p. 47), who revised, as he said, the available biostratigraphic data on the Danian and Montian stratotypes, concluded that the Montian is an equivalent of the Danian and, therefore, cannot be accepted as the "standard global stratigraphic unit." The same *available biostratigraphic*

data were evaluated by Steurbaut (1998, pp. 143–144) in the following way: "The uppermost Danian beds have not been comprehensively studied in Belgium,..." "the Danian deposits of northeastern Belgium are studied to a lesser extent,"... "biostratigraphic substantiation of the base and top of the Montian seems to be very insufficient," and so on.

In our opinion, "the biostratigraphic substantiation" of the Montian Stage distinguished near the town of Mons is a peculiar assemblage of bivalves and gastropods associated with other macrofossils, first of all, with echinoids of the genus *Echinanthus* (Naidin and Ben'yamovskii, 1988, pp. 6–9). In the Montian stratotype, the vertical range of these faunal groups is difficult to determine because of the gradual lithological and faunal transition from the underlying Danian deposits and also owing to the replacement of marine beds by continental ones at the top (Fig. 1) (Marliére, 1964, 1977; Godfriaux and Marliére, 1971; Robaszynski, 1979, 1981).

The individual characteristics of Montian and Danian faunal assemblages was thoroughly studied by Vincent (1928) in the section of Mine no. 2 near the town of Eisden (the Limbourg Province), 250 km to the northeast of Mons. This section is reproduced in Fig. 5 of Moskvin and Naidin (1960).

To the east, the Montian deposits are widespread in a vast latitudinal area from the southern part of the European paleobiogeographic province and adjacent areas of the northern Tethys up to the Amu Dar'ya River and Tajik depression (Kakhanova and Yarkin, 1966; Davidzon *et al.*, 1982; Naidin and Ben'yamovskii, 1989). Within this region, there is a number of sites, where the Montian deposits are relatively well studied. These are the Vistula River site in Poland, the Crimean Mountains, the Kheu site of the Northern Caucasus, and the Mangyshlak Mountains.

Another shortcoming of the Montian stratotypes is their inaccessible position in mining exposures (mines, well, and boreholes) although the stratotype deposits are well documented and sampled, and specimens of fossil are carefully stored in different institutions of Belgium. Marliére (1962) rightfully invited different specialists to study the Montian stratotype by examining abundant museum collections. However, it is evident that seemingly complete descriptions and graphs, as well as collections stored in the ideal conditions, cannot substitute "the nature", i.e., the exposures exhibiting the base and top of the stratigraphic unit under consideration.

THE CRIMEAN MOUNTAIN SECTIONS SUPPLEMENTING THE MONTIAN STRATOTYPE

For the reasons indicated above, we should draw attention to natural outcrops of the Crimean mountains, Northern Caucasus, and Mangyshlak mountains. There we can choose the most typical sections supplementing the Montian stratotype. Naturally, sections in the mentioned regions have their own advantages and disadvantages. The common advantage is their location in the European paleobiogeographic realm. It should be noted that the proposition of Salaj (1980, pp. 145–146) to take the El Haria section of Tunisia as the Montian hypostratotype cannot be accepted because it is located in the other paleobiogeographic area of the Tethys away from the Montian stratotype locality.

The southwestern Crimean Mountains are most suitable among three regions listed above. There 40–45-km interval of the steep, locally scarped cuesta in the second ridge of the Crimean Mountains exhibits a continuous sequence of the Maastrichtian, Danian, Montian and Thanetian deposits. The Selandian deposits are supposed to occur here as well. The transverse dissection of the cuesta scarp by the Bel'bek, Kacha, Churyuksu and Bodrak river valleys facilitates tracing the bed succession (Naidin, 1964, Fig. 1).

The Danian and Montian deposits occur in a single succession, the general structure of which is shown in Fig. 2. The Danian bryozoan limestones with *Crania* and *Echinocorys* are easily distinguishable from the Montian organic–detrital and foraminiferal limestones with peculiar conchiofauna and echinoids of the genus *Echinanthus*. The beds are thinned out northeastward, near the transverse Simferopol Uplift (Muratov, 1949). The thickness decreases owing to the increasing number of hiatuses confined to the "hardground" levels (HG) characteristic of the sequence (Fig. 7).

The bed succession is separated from the underlying Upper Cretaceous (upper Maastrichtian) deposits by different submarine "hardground" levels deserving a special description. In the Bodrak River valley, these levels are replaced by the submarine erosion surface (Fig. 2). The submarine origin of the Maastrichtian–Danian contact excludes any considerable stratigraphic hiatus.

As for the contact between the "binome Danien–Montien" and the upper Paleocene (Thanetian marls), there is a noticeable stratigraphic hiatus resulted mainly from subaerial erosion.

The Bakhchisarai Section

By the present time, the sequence is best studied in the continuously exposed Starosel'e (Salachik)–Suvlukaya section at the right slope of the Churyuksu River valley above the eastern suburb of the town of Bakhchisarai (Vyalov, 1976; Naidin, 1964; *Putevoditel...*, 1971). The section has been known to many generations of geologists since the early XIX century and 90 years ago Lange and Mirchink (1909), who summarized previous materials and personal field observations, recognized there the *Danian* and *Montian* stages. Later on, during many decades, the Paleogene deposits of the Bakhchisarai area were revised many times during the student geological practice.

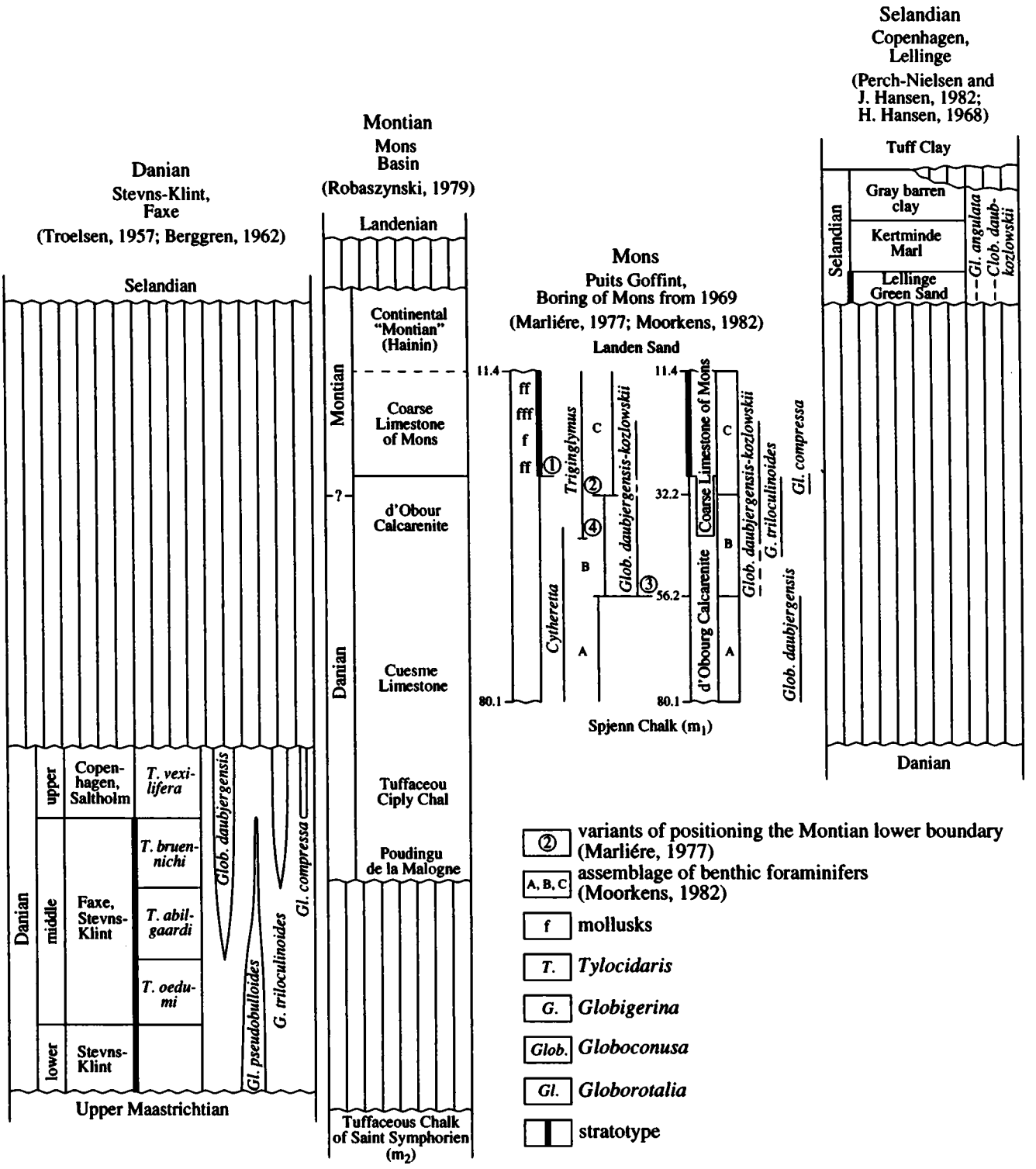


Fig. 1. Supposed positions of the Danian, Montian and Selandian stages in the stratigraphic succession (after Naidin and Ben'yamovskii, 1988)

The former capital of the Tatarian Khanate in Crimea became most popular in the Russian geological literature (and, regretfully, in the state geological mapping), when the concept of the "Bakhchisarai stratotype section of the Paleogene" had been elaborated (*Resolution...*, 1963, pp. 146–147).

Deposits above Starosel'e (the eastern suburb of Bakhchisarai; Fig. 3) are exposed in the follow-

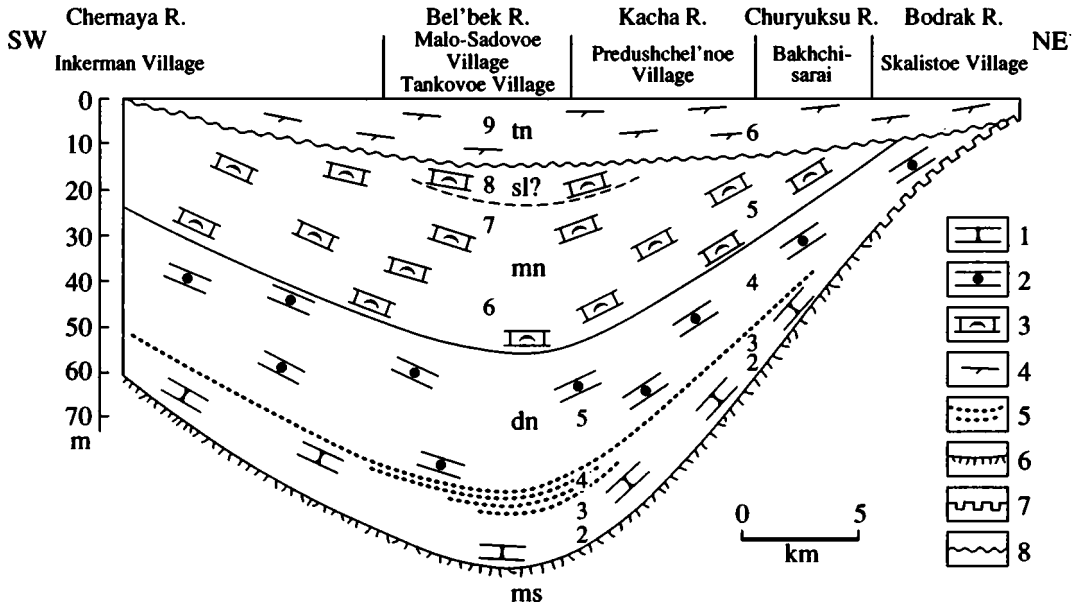


Fig. 2. Cross section of the lower Paleocene in the southwestern Crimean Mountains: (1) predominantly bryozoan limestone (silty or sandy in the lower part, enclosing basal beds of glauconitic-calcareous siltstone or fine-grained sandstone) with oysters and small echinoids; (2) bryozoan–crinoid limestone (ratio of rock-forming component is greatly variable) with *Crania* and *Echinocorys*; (3) organogenic-detrital and foraminiferal limestone with different bivalves, gastropods (locally very abundant), and echinoids of the genus *Echinanthus*; (4) marl; (5) chert; (6) "hard ground" level; (7) submarine erosional surface; (8) predominantly subaerial erosional surface; (ms) upper Maastrichtian; (dn) Danian; (mn) Montian; (sl?) supposed Selandian; (tn) Thanetian (figures designate bed numbers).

ing succession (from the base upward) (Figs. 4 and 5):

Upper Maastrichtian

(1) Glauconite-bearing fine-grained marly sandstones (siltstones); the rocks are light gray, when dried, with numerous fucoids. Three meters below the bed top, there is a horizon up to 0.1 m thick ("a" in Fig. 4) that yields abundant oyster and pectinid valves, and also phosphatized shells of bivalves and gastropods.[1] Above the horizon "a" abundant oyster and pectinid valves are locally concentrated in "banks". The unit thickness is 9 to 10 m. At the top of Bed 1 there are pockets and hollows up to 0.5–0.7 m deep, which are filled with the sandstone of Bed 2.

Danian

(2) Light gray hard limestones; in their lower part, the rocks are light greenish gray, enclosing glauconite grains. The basal bed (0.3–0.4 m) of green loose glauconitic–calcareous sandstone yields phosphatized molluscan shells, oyster valves, and scarce belemnite rostra (reworked like some oyster valves). The bed thickness is 2.8 m.

(3) Light gray soft bryozoan limestones with black chert interbeds in the upper part ("b"); the bed shows signs of domestic mining. The bed thickness is 6.5–7 m.

(4) Light gray hard (especially in the upper part) organogenic–detrital (bryozoan–crinoid) limestone with lenses and lenticular interbeds overfilled with crinoid columnals. The bed thickness is 15–16 m.

Montian

(5) Pinkish yellow, very hard organogenic–detrital limestone producing stepwise outcrops on the slope. Thin laminae and lenticles of white powdery material are confined to characteristic uneven bedding planes. Bed 5 is 16–18 m thick and has uneven upper surface lacking traces of "burrows" and corresponding to the structural terrace surface.

Thanetian

(6) Light gray to yellowish dense marl slightly sandy in the lower part and containing glauconite grains at the base; higher (horizon "c" in Fig. 4), the rock contains gray and dark gray siliceous pseudomorphs after sponges ("spongy horizon" of M.E. Zubkovich). Bed 6 is 13–14 m and shows uneven upper surface with "burrows" filled with overlying sedimentary material.

[1] Generic names of mollusks correspond to those given by Gorbach, 1972.

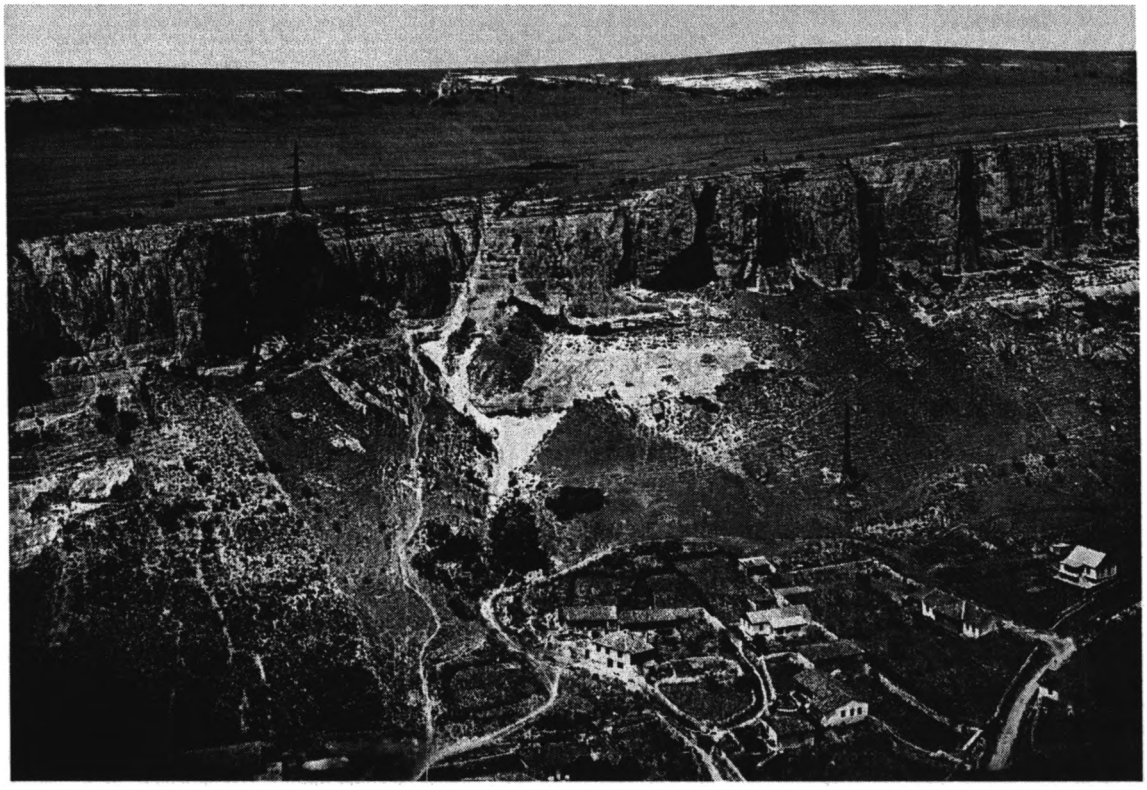


Fig. 3. The Starosel'e area: white on the gentle slope are the upper Maastrichtian deposits (Bed 1); Danian and Montian limestones (Beds 2–5) are exposed in the scarp. (Bed 5) the structural terrace surface corresponds to the top limestone succession.

Ypresian

(7) Brownish to dark gray calcareous clay; in the basal part (0.2 m), the rock is dark green, sandy, enriched in glauconite grains, and containing scattered phosphoric nodules. The bed thickness is 17–18 m.

Beds 1–5 known in literature as the **Starosel'e (Salachik) succession** are exposed at the right bank of the Churyuksu River above the eastern suburb of Bakhchisarai at the joint of the Bol'shaya Koz'ya and Malaya Koz'ya valleys (Biyuk-Ashla-Madere and Kichik-Ashla-Madere).

Beds 5–7 are exposed at the steep, locally scarped right slope of the Churyuksu valley. The site is called by Tatars as *Suvlukaya* ("wet rock"), because clay of Bed 7 retain the rain water leaking for a long time along the slope (Naidin and Ben'yamovskii, 1994).

The Bel'bek Section

More complete sections of the "binome Danien–Montien" are located in the Bel'bek River valley between the Malo-Sadovoe and Tankovoe villages (Gorbach,1972; Naidin, 1964). The most informative and easily accessible outcrops are in the steep slopes of the cuesta scarp above the Malo-Sadovoe Village and in the both Bel'bek banks near the Tankovoe Village.

The composite section comprises the following beds (from the base upward):

Upper Maastrichtian

(1) Greenish gray calcareous–glauconitic siltstone (fine-grained sandstone); the bed yields *Neobelemnella kazimiroviensis* (Skolozdr.), *Hoploscaphites* ex gr. *constrictus* (Sow.), *Pycnodonte mirabile* (Rouss.), *Chlamys (Microchlamys) acuteplicata* (Alth), and others.

Danian

One "hardground" level is confined to the top of Bed 1, and the doubled "hardground" with reworked belemnite rostra occurs in the Zelenaya Ravine at the right Bel'bek bank downstream of the Malo-Sadovoe Village.

(2) Greenish gray calcareous–glauconitic siltstone (fine-grained sandstone); the rock yields *Deuteromya paulula* Gorbach, small oysters, echinoids *Pseudogibbaster akkajensis* (Web.) Posl. et Moskv., and *Hemiaster inkermanensis* Loriol. The bed thickness is 2.3–3 m.

(3) Light, yellowish gray bryozoan–crinoid limestone silty and greenish gray in the lower part of the bed; mollusks *Pycnodonte beshkoshensis* (Web.), *P. similis* (Push), and *P. vesicularis* (Lam.) are most common fossils of the rock. They are found together with

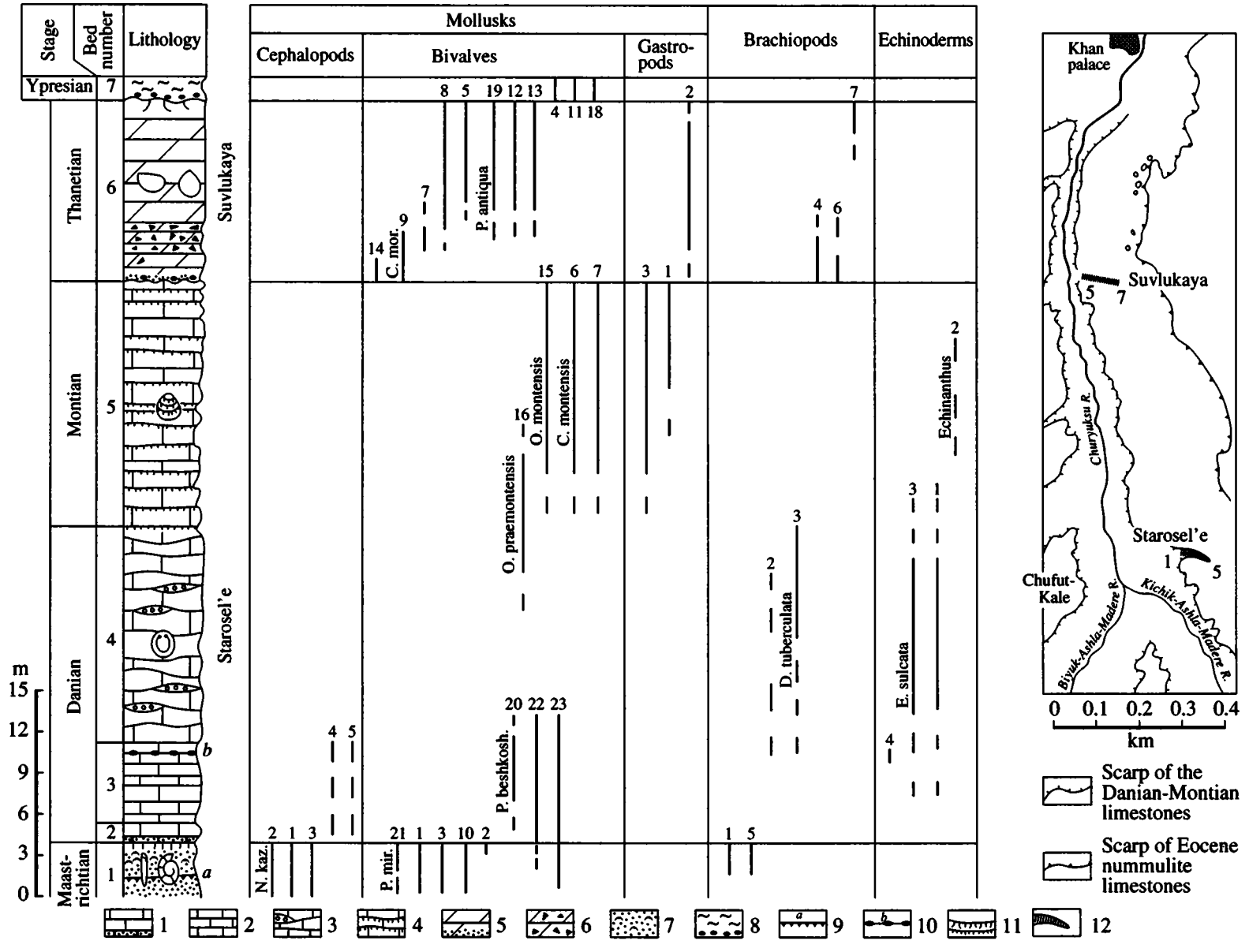


Fig. 4. Stratigraphic ranges of macrofossils in the Starosel'e section: (1) limestone basal glauconitic–calcareous sandstone; (2) bryozoan limestone, Bed 2; (3) hard bryozoan–crinoid limestone with lenses of abundant crinoid remains; (4) very hard organogenic-detrital limestone; (5) basal sandy marl with phosphorites; (6) marl with cherts; (7) carbonate sand with abundant oyster shells; (8) carbonate clay with the basal phosphorite-sandy horizon; (9) horizon *a* of phosphatized gastropod and pelecypod shells; (10) black chert, horizon *b*; (11) "hard ground" (HG); (12) considered sections; figures designate paleontological remains listed in Appendix.

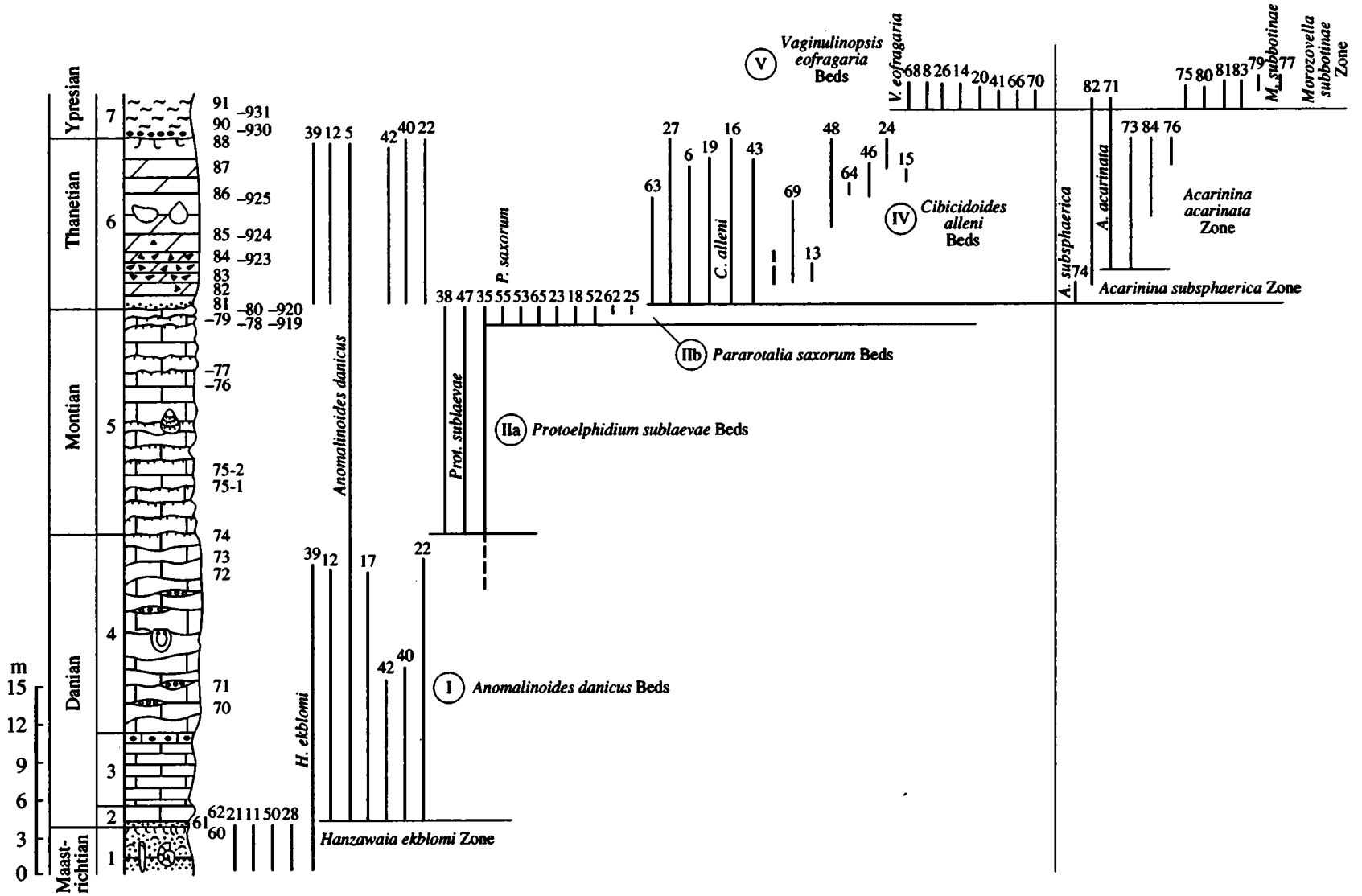


Fig. 5. Stratigraphic ranges of microfossils in the Starosel'e section (symbols as in Fig. 4; encircled Roman figures are numbers of beds with benthic foraminifers; Arabian figures designate species listed in the Appendix).

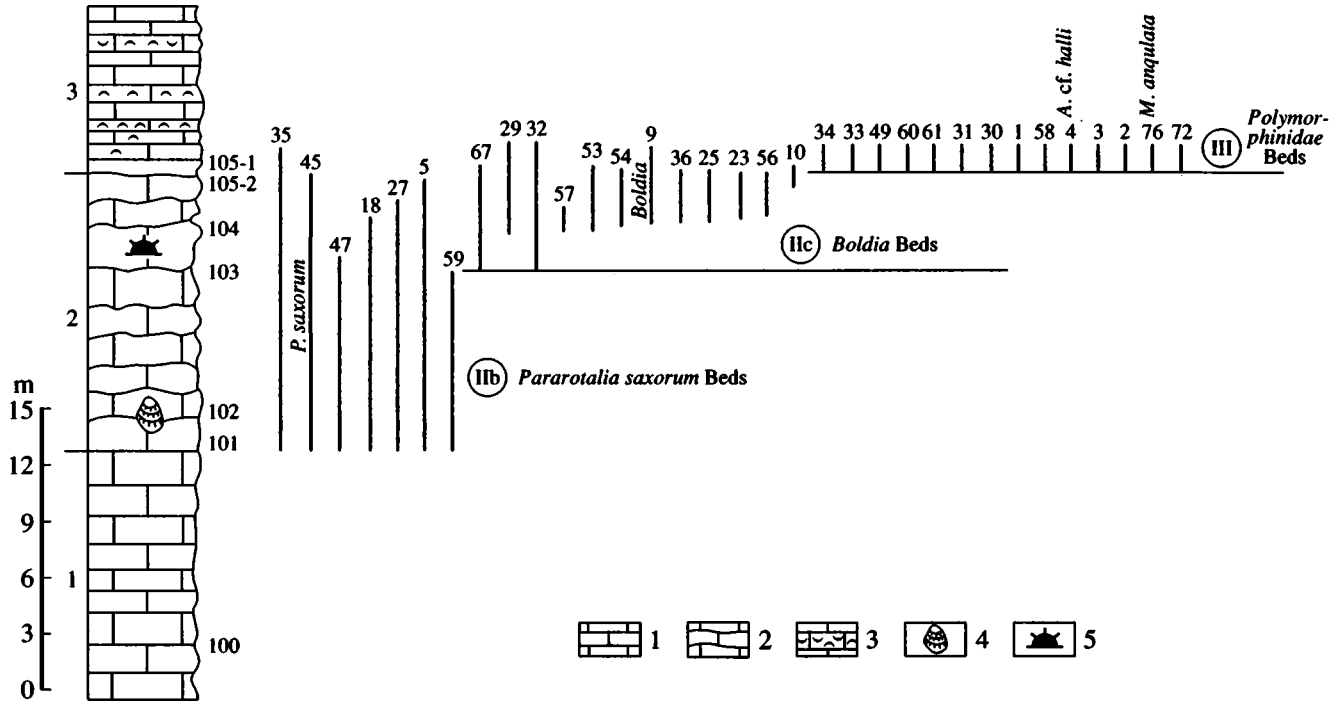


Fig. 6. Stratigraphic ranges of microfossils in the Bel'bek section: (1) organogenic–detrital limestone; (2) wavy-bedded limestone; (3) limestone with abundant bivalves and gastropods; (4) Montian bivalves; (5) Montian echinoderms; encircled Roman numbers are for beds with benthic foraminifers; Arabian figures designate species listed in Appendix.

nautiloids *Pseudocenoceras warsanofievie* Shim. and *Teichertia similis* Shim. Gorbach (1972, p. 21) reported on occurrence of *Turritella vialovi* Gorbach. Echinoids *Ps. akkajensis* (Web.) Posl. et Moskv., *H. inkermanensis* Loriol, and others are characteristic of the rock. The bed thickness is 10–11 m.

(4) Predominantly bryozoan white limestone enclosing 6–8 chert horizons. Bivalves are represented by *Isocardia faxensis* Lundgr., *Plicatula*, pectinids, and others. Gastropods are more diverse being represented by different *Cerithium* and *Turritella* forms associated with *Monodonta quadricordata* Ravn, *Campanile maximum* (Binckh.) *Crommium ciplyensis* (Vinc.), and others. Rare cephalopods *Pseudocenoceras warsanofievie* Shim. and unidentifiable remains of *Crania* occur here as well. Echinoid group includes, in addition to forms inherited from Bed 3, the newcomers *Echinocorys sulcata* Goldf., *Ech. obliqua* Ravn, and *Pseudogibbaster depressus* (Kong.). According to Gorbach *et al.* (1974), Bed 4 yields spines of *Tylocidaris rosenkrantzi* Brotzen. The bed thickness is 8 m.

(5) White to grayish white crinoid–bryozoan limestone; the rock is coarsely bedded in the upper part. Identifiable mollusks are represented only by *Plicatula praecyclostroides* Gorbach, *Lima holzapfeli* Hennig, and *Ostrea praemontensis* Gorbach, the latter appearing in the upper part of the bed. *Danocrania tuberculata* (Nilss.), *Isocrania posselti* Rosenkr. (Rosenkrantz, 1964; Titova and Favorskaya, 1983), and other *Crania* forms together with shells of articulate brachiopods are of the greatest stratigraphic value. Echinoids inherited from the underlying bed become more abundant. Spines of *Tylocidarys* were also found. The diverse *Serpula* forms are represented by straight *Ditrupa schlotheimi* (Rosenkr.) and spiral *Glomerula gordialis* Schloth. and columnals of *Bourgueticrinus danicus* Br. Nils. are defined among crinoids. The bed thickness is 25–28 m.

Bed 5 grades upward without apparent hiatus into Bed 6.

Montian

(6) Light yellowish gray and very hard organogenic–detrital limestone locally including accumulations of small oyster valves and shells of unidentifiable pelecypods and gastropods; Gorbach (1972) reported about *Ostrea montensis* Cossm., *O. praemontensis* Gorbach, *Corbis corneti* Vinc., *C. inkermanensis* Gorbach, *C. montensis* Cossm., *Turritella montensis* Br. et Corn., and *Echinanthus* sp. occurring in the bed. All listed mollusks, except for *O. praemontensis* passing from below, are confined to the upper part of the bed. The bed thickness is 15–20 m.

(7) Thick strata of pinkish yellow hard limestones intercalated with interbeds of less hard rock varieties; wavy bedding and lenticular interbeds with abundant fossil bivalves and gastropods are characteristic. In

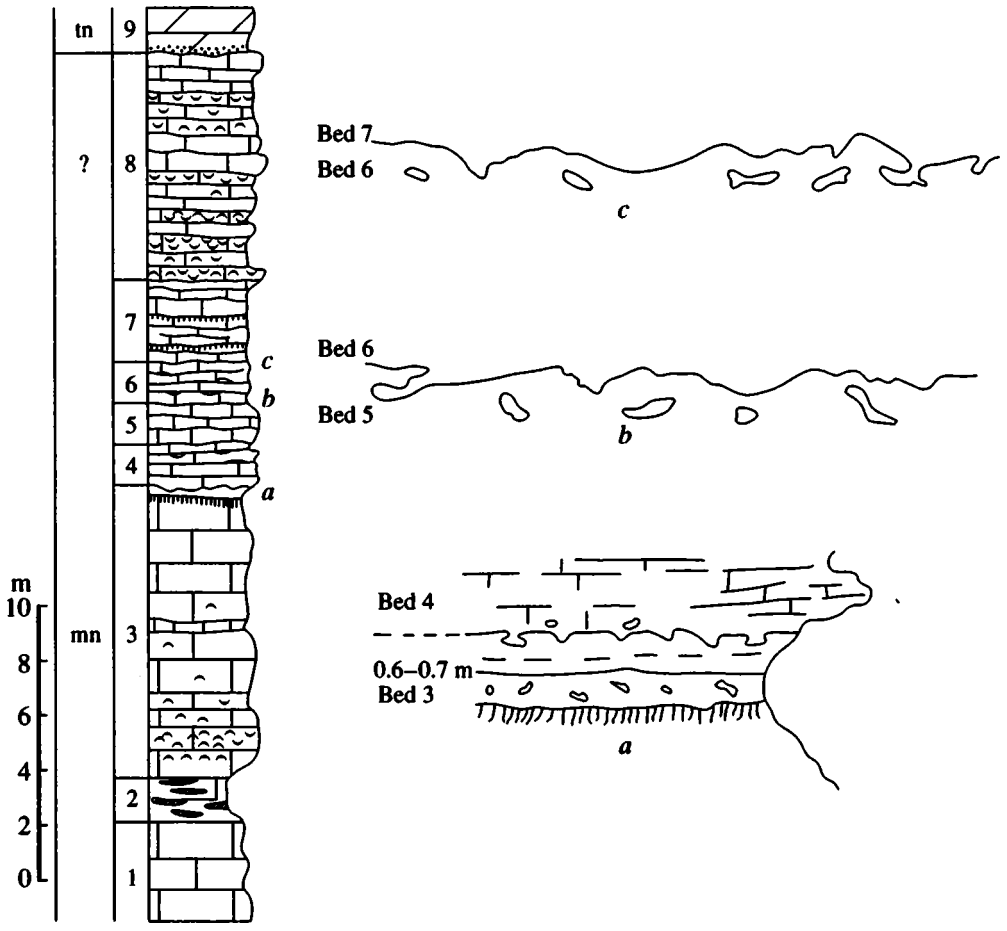


Fig. 7. The Montian limestone section in the left bank of the Bel'bek River near the Tankovoe Village: (mn) Montian; (?) supposed Selandian; (tn) Thanetian; (1–9) bed numbers; (*a*–*c*) "hard ground" levels separating some beds; (1) yellowish and grayish massive limestone; (2) gray limestone with light gray elongated lenses of irregular cementation in opinion of Gorbach (1.5–1.8 m); (3) limestone similar to that of Bed 1 but somewhat harder, enclosing one softer limestone interbed and doubled HG at the top (10–11 m); (4) platy limestone with uneven bedding planes and big "caverns" filled by relatively soft limestone (1.5 m); (5) massive sheepback limestone (1.5 m); (6) limestone similar to that of Bed 4 (1.5–1.6 m); (7) limestone with very uneven bedding planes, surface of which resembles a cauliflower (the "cabbage" structure) and looks from a distance like the boulder accumulation (3–3.2 m), beds 4–7 are light yellowish gray, slightly pinkish; (8) grayish pink, hard, thick-platy limestone with wavy bedding and local accumulations of small bivalves and gastropods in individual interlayers (8–9 m); (9) light gray sandy marl with glauconite grains in the lower part; wavy and uneven bedding indicate "blurred" HG.

addition to fossils typical of Bed 6, the bed yields *Crassatella excelsa* Cossm., *Venerecardia excellens* Gorbach, *Phacoides montensis* Cossm., *Pitar montensis* (Cossm.), and some other mollusks, as well as *Echinanthus* forms. The bed thickness is 16–18 m.

(8) Pinkish gray coarsely bedded limestone with lenticular interbeds of white viscous limestone, which are siliceous in the upper part; abundant mollusks of the bed are classed with *Isognomon belbekensis* Gorbach, *Lima dotata* Gorbach, *Cerithium semicostatum* Desh., *Turritella montensis* Br. et Corn., and *T. acuta* Br. et Corn. The bed thickness is 6–8 m.

The molluscan assemblage of Bed 8 is typical of the Montian Stage. However, the uppermost position of the bed in the limestone sequence and micropaleontological data (see below) may indicate the Selandian age of the Bed 8.

Due to recrystallization, limestones of Beds 6–8 yield badly preserved faunal remains (predominantly casts and imprints). In addition, hardgrounds, which apparently are abundant inside limestones (Fig. 7), are blurred in these beds, and bedding planes are indistinct.

Thanetian

(9) Light greenish gray silty marl; the rock is glauconitic at the base and colored light gray at the top. The surface of underlying limestone (Bed 8) is without fucoids. The marl yields typical Thanetian fauna of mollusks (Naidin, Ben'yamovskii, 1994).

Regretfully, the characteristics of macrofaunas from the Bel'bek section has not been supported by bed-by-bed micropaleontological analysis. Available for this analysis were only samples from the outcrop at the right bank of the Bel'bek River near the Tankovoe Village, where the exposed beds approximately correspond (no precise correlation has been made) to Beds 7–8 of the section described. Samples from the lower part of the outcrop (*Pararotalia saxorum* Beds in Fig. 6) yielded *Pararotalia saxorum* (d'Orbigny), *Protoelphidium sublaevae* (Ten Dam), *Cibicidoides cuvillieri* (Ten Dam), *Gavelinella lellingensis* Brotzen, *Anomalinoides danicus* (Brotzen), *Schlosserina astericus* (Gümbel). Appearing higher in the section (*Boldia* Beds) are *Vacuvalvulina keijzeri* (van Bellen), *Rotorbinella mariei* (van Bellen), *Rotalia marginata* d'Orbigny, *Eponides toulmini* Brotzen, *Elphidiella prima* (Ten Dam), *Boldia* sp., and *B. variabilis* Szczechura et Pożaryska.

As compared with the Montian foraminiferal assemblage from the Bakhchisarai (Starosel'e–Suvlukaya) section, that of the Bel'bek section is more diverse and includes forms from the *Boldia* Beds missing from the Bakhchisarai section.

At the next higher level, the assemblage of benthic foraminifers typical of the Polymorphinidae Beds was found. This assemblage includes *Guttulina problema* d'Orbigny, *G. hantkeni* Cushman, *Pirulina fusiformis* Roemer, *Globulina rotundata* Borneman, *Alabamina midwayensis* Brotzen, and *Allomorphina* cf. *halli* Jenning, and associated planktonic foraminifers *Morozovella angulata* (White) and *Acarinina praecursoria* Morozova. The assemblage is clearly distinct from the preceding ones by almost complete disappearance of the Montian forms, being identical to that described by Brotzen (1948) from the Selandian deposits of the stratotype area. It is significant that the planktonic foraminifers also indicate the Selandian age of the host sediments because *Morozovella angulata* was defined by Hansen (1968) in the Selandian stratotype.

Thus, the micropaleontological data, as well as the geological structure show that the Bel'bek section is more complete than that of the Bakhchisarai site (Fig. 2). The combined data on distribution of micro- and macrofauna in the Bel'bek River succession between the Malo-Sadovoe and Tankovoe villages make it possible to reliably trace the Montian–Selandian boundary.

Biostratigraphic Characterization of the Danian and Montian Stages in the Crimean Mountains

Echinoid remains are of prime significance for the Paleocene stratigraphy in the Crimea–Caucasus region (Poslavskaya and Moskvin, 1959, 1960). Regretfully, the Danian and Montian echinoids collected in the Crimean Mountains remain inadequately studied. Nevertheless, the species evolution of the genus *Pseudogibbaster* Moskvin (Moskvin, 1983) allows the recognition of the *Pseudogibbaster akkajensis* Zone (Beds 2 and 3 of the Bel'bek section and Bed 2 of the Bakhchisarai section) and the *Pseudogibbaster depressus* Zone (Beds 4 and 5 and Beds 3 and 4 respectively) in the Danian deposits of the southwestern Crimean Mountains.

The rare and poorly preserved *Echinanthus* forms appeared to be additional guide fossils of the Montian deposits in Crimea. At present, *Echinanthus* species from the Bel'bek section are defined by Moskvin with marks "cf." and "aff.," but there is no doubt that the further collection and study of echinoids can provide an important tool of stratigraphic subdivision of the "binome Danien–Montien" in the Crimea.

In the Crimean mountains, there is a *regional* hiatus between the upper Maastrichtian and Danian deposits and above the HG level at the top of the Maastrichtian succession. The hiatus span increases from the Bel'bek River valley, where the Danian–Montian deposits are represented most fully, toward the northeast by approaching the Simferopol Uplift (Fig. 2). Near the Skalistoe Village and in the Bakla Cave Town in the Bodrak River valley, the typical HG zones are replaced by a peculiar uneven surface with deep pockets originated during the submarine erosion (Fig. 2). As a result, the *Pseudogibbaster akkajensis* Zone is almost completely missing from the Danian succession.

According to the three-member subdivision of the Danian Stage in Denmark suggested by Brotzen (1959)[2] and also on the basis of *Tylocidaris rosenkrantzi* spines occurring in the lower Danian of the Crimea, Gorbach *et al.* (1974) suggested the middle–upper Danian age for the Crimean bryozoan–crinoid limestones. This suggestion is consistent with data on the Crimean *Crania* forms, which are similar to those known from the middle–upper Danian of Denmark (Titova and Favorskaya, 1983).

In addition to *Crania* fauna, the Danian deposits in the Crimean Mountains contain a diverse assemblage of articulate brachiopods dominated by new species (Gorbach and Zelinskaya, 1975). The Montian brachiopod fauna in the Crimea is extremely poor. Gorbach and Zelinskaya (1975, p. 68) reported only on three brachiopod species from the Montian beds exposed near the Tankovoe Village at the Bel'bek River and near the town of Kubalach of the Belogorsk area. The same species are also known from the lower Paleocene deposits of Mangyshlak and northern Ukraine.

Among 37 bryozoan species (order Cheilostomata) from Danian beds of the Crimea, 26 are known as well from the Danian Stage of Denmark. Because the crinoid–bryozoan limestones of the southwestern Crimean Mountains yield a lot of bryozoan species in

[2] The lower Danian corresponds to the *Tylocidaris ödumi* Zone, the middle Danian to the *Tylocidaris rosenkrantzi* and *Tylocidaris brünnichi* zones, and the upper Danian to the *Tylocidaris herupensis* Zone.

Table 3. Thickness relationship between Danian and Montian carbonate deposits

Section / Stage	Shallow-water deposits, m						Deep-water deposits, m	
	Crimean Mountains				Mangyshlak Mountains		Central Ciscaucasia	Austria
	Southwest			Center	N. Aktau	S. Aktau		
	Inkerman	Bel'bek	Starosel'e	Indol	Kaurtakapy	Sulukapy	Kheu	Salzburg*
Montian	24	40–45**	16–18	20	10	19–20	10	30
Danian	37	45–50	24–26	40	75	40–42	12	90

* After Gohrbandt (1963).

** Probably, including the Selandian (?).

common with the tuffaceous Ciply Chalk (upper Danian) of Belgium, the suggestion was made that "the Danian deposits of the southwestern Crimea are partly or fully analogous of the tuffaceous Ciply Chalk" (Bykova *et al.*, 1969, p. 145).

The lower horizons of the Danian sections of the Crimea can be easily distinguished by **conchiofauna** remains. The horizons contain a characteristic assemblage of oysters showing their connection (despite the stratigraphic hiatus!) with the late Maastrichtian ancestors. Vyalov and Gorbach (1982) recognized the horizons as the oyster *Pycnodonte beshkoshensis* Zone corresponding partly or fully to the *Pseudogibbaster akkajensis* Zone.

The stratigraphic range of *Ostrea praemontensis* described by Gorbach (1972; p. 60) can characterize the corresponding zone (beds) spanning the upper Danian (from the upper part of Bed 5 in the Bel'bek section to the upper part of Bed 4 of the Bakhchisarai section) and the lower Montian (Bed 6 in the Bel'bek section, and the lower part of Bed 4 in the Bakhchisarai section). Only few molluscan species (including *Ostrea praemontensis*) cross the Danian–Montian boundary (Gorbach, 1972). In general, the Montian and Danian molluscan assemblages are so different that the former is much more diverse and abundant. In the sections studied, the particular beds (Bed 7 of the Bel'bek section and Bed 5 of the Bakhchisarai section) overlying the *Ostrea praemontensis* Zone or beds (Bed 6 of the Bel'bek section, the upper part of Bed 4 of the Bakhchisarai section) can be recognized as the *zone of typical Montian* mollusks.

Oysters, some local endemic species included, have a particular value for the Danian and Montian biostratigraphy and paleobiogeography in the European paleobiogeographic realm. *Ostrea montensis* Cossm. can be used for the interregional correlation of Montian deposits within the enormous territory of the Belgian basin, platform areas of Ukraine, the Crimea, and Kopetdag (Vyalov and Gorbach, 1982, p. 101; Gorbach and Shekhotkin, 1979, p. 52). The Danian–Montian boundary is virtually drawn at the last occurrence level of *Crania* forms, where abundant conchiofauna appears, or, to be more precise, where the Montian *Echinanthus* replaces the Danian *Echinocorys*.

Foraminifers represent also a very important group for the Paleocene stratigraphy in Crimea (Shchutskaya, 1958, 1960, 1970; Yartseva, 1966, 1973; Maslakova and Nguen van Ngok, 1975; Pożaryska and Szczechura, 1970).

According to succession of benthic foraminifers, the Montian deposits of Belgium are subdivided into three complexes: lower (A), middle (B), and upper (C). The lower complex is an equivalent of the tuffaceous Ciply Chalk (Moorkens, 1982). We divided the Montian deposits of Crimea, using distribution ranges of benthic foraminifers, into the lower (*Protoelphidium sublaevae* Beds), middle (*Pararotalia saxorum* Beds), and the upper (*Boldia* beds) units (Figs. 5 and 6). The middle and lower units can be correlated with the middle complex(B) on the basis of common species, such as *Anomalinoides danicus, Boldia* sp., *Pararotalia saxorum, Epistomaria budensis, Rotalia marginata*, and *Vacuovalvulina keijzeri*.

There are some data on occurrence of small nummulities in the Danian limestones of the Bakhchisarai and Bel'bek sections (Ashurov and Nemkov, 1991, p. 465) and of *Nummulites soliturius* Harpe in the Montian limestones near the Predushchel'noe Village at the Kacha River (Makarenko, 1961, p. 21). However, these data should be verified. The significance of **ostracods** for the Danian and Montian stratigraphy in the Crimean Mountains was reviewed by Naidin and Ben'yamovskii (1988, pp. 8–11, 1989, pp. 26–27).

Parametric Characteristics of Danian and Montian Deposits

The doubled limestone sequence consisting of the lower relatively soft bryozoan limestones with *Crania* forms and of the upper much denser limestones with *Crassatella* sp., *Corbis* sp., and *Turritella* sp. was discovered by pioneering investigations of the Crimean geology (Prendel, 1876, p. 87; Stukenberg, 1873, p. 70, Fig. 7). Later, Lange and Mirchink (1909) attributed the

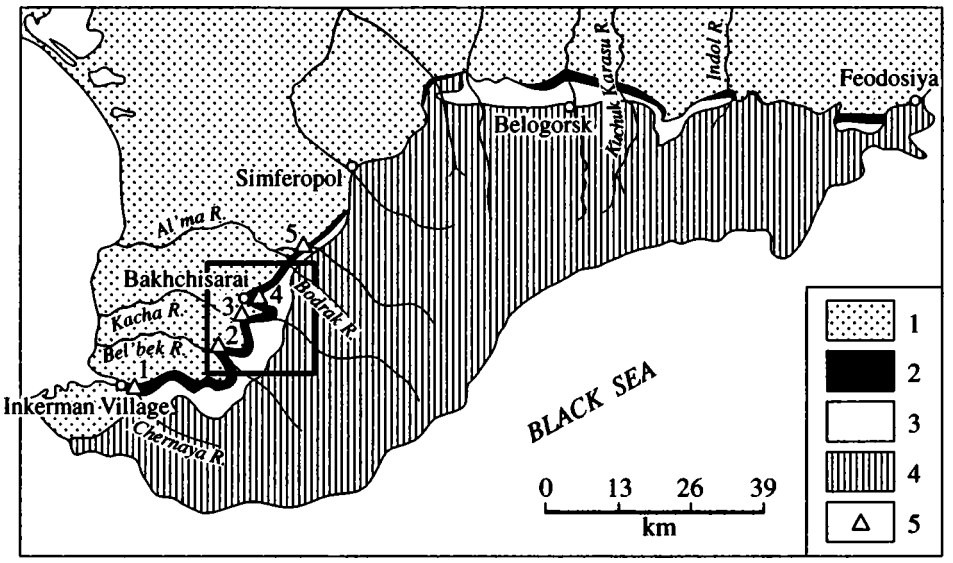


Fig. 8. Distribution of Danian and Montian deposits in the Crimea: (1) Cenozoic; (2) Danian and Montian; (3) Upper Cretaceous; (4) pre-Upper Cretaceous; (5) Danian and Montian sections in the southwestern Crimean Mountains: (1) Chernaya River (Inkerman Village), (2) Bel'bek River (Malo-Sadovoe and Tankovoe villages), (3) Kacha River (Predushchel'noe Village), (4) Bakhchisarai (Churyuksu River), (5) Bodrak River (Skalistoe Village). The suggested reference section site is framed.

Crania-bearing limestones to the Danian and the beds with *Crassatella* to the Montian.

There is a distinct change in composition of rock-forming components across the Danian–Montian boundary. The crinoid–bryozoan remains disappear from the Montian beds of the Crimea. Only eight of 37 bryozoan species described from the Danian deposits were found in the Montian beds. Both the Danian and Montian limestones of the Crimea are organogenic–clastic, but they differ in proportions of particular clastic components, such as fragments of molluscan valves, foraminiferal shells, and skeletons of red algae. Some other fossil remains may also be the constituents of Danian and Montian limestones in the Crimea. For instance, Korde (1975) reported on small skeleton fragments (observable only in thin sections) of peculiar animals belonging to the class Hydroconozoa and associated with the rock-forming calcareous algae, bryozoans, echinoids, and foraminifers in the Danian–Montian limestones of the Starosel'e section.

Thus, there are paleontological and lithological differences between the Danian and Montian limestones. One peculiar lithological feature should be mentioned: although the Montian limestones occur above the Danian deposits, they are strongly recrystallized (their "crystalline state" was noted long ago by Lange and Mirchink, 1909) and considerably "harder" than the latter. The bedding plane separating these units corresponds to the surface of the "Montian–Danian" cuesta known for many generations of students. It is not an accident that quarries of Danian building stones are located in the Bodrak River valley, where they are not "armored" by the "harder" Montian beds (Fig. 2).

In the southwestern Crimea, the Danian and Montian limestones different in paleontological content and lithological features represent the apparently continuous succession. A possible (insignificant) hiatus has not been discovered there. However, in the central part of the Crimean Mountains, there is a well pronounced hiatus between the Danian and Montian deposits (Makarenko, 1961, Fig. 2; Naidin, 1964, Fig. 4). Gorbach and Shekhotkin (1982) described a subaerial elluvium bed between the Montian and Danian limestones at the Kuchuk-Kurasu River.

The data on the Crimean mountains show that, two successive stratigraphic units can be recognized here: the lower unit with the Danian fauna and the upper one with the Montian fauna (Fig. 2). The Crimean succession does not confirm the inference made from the discrete fragmental "sections" of Western Europe that the Danian and Montian deposits were fully or partly the facies varieties. The Crimean carbonate succession and Danian–Montian deposits in some other regions demonstrate **comparable stratigraphic ranges of the Danian and Montian stages, though the Danian slightly exceeds the Montian** in this aspect (Table 3).

Our tentative estimates showed the relatively uniform rates of carbonate (probably, more correctly limy) sedimentation. Accordingly, the time ranges of the Danian and Montian should be approximately proportional to their thickness.

According to Berggren *et al.* (1995), the Danian Age lasted 4.1 m.y. (Table 1). As shown above, P2 corresponds to the Montian. Berggren *et al.* (1995) estimated the duration of P2 (i.e., of the Montian) as equal to 0.4

m.y. in contrast to the value of 0.7 m.y. obtained earlier. Preliminary measurement results for the Danian and Montian carbonate successions do not confirmed such a "short" duration of the Montian.

We should repeat once again: **the Danian and Montian stages are comparable in thickness, although the Danian deposits are somewhat thicker, and consequently, the time period of their formation was longer.**

ONCE MORE ABOUT THE INDEPENDENT MONTIAN STAGE AND STAGE SUBDIVISION OF THE PALEOCENE

Each of two (Danian and Montian) stages is characterized by specific assemblages of macrofauna. The Montian fauna is not a direct progeny of the Danian one as it is evident from compositional differences between both. Therefore it is incorrect to interpret the Montian time as a final phase of the Danian fauna evolution and, correspondingly, to take the Montian for the upper part of the Danian Stage.

The independence of the Montian Stage and its equivalence to the Danian Stage is also evidenced by a wide distribution of Montian macrofauna from the European coast of the Atlantic Ocean in the west to the Amu Dar'ya River and Tajik depression in the east. This fauna characterizes the stratigraphic unit persistent over the enormous territory. Homotaxy and facies-dependent confinement of the fauna should be rejected in this case. The main objective of this article was to support our earlier efforts to prove the independence of the *Montian Stage* (Naidin and Ben'yamovskii, 1988, 1989).

The Selandian Stage incorporated in the standard scale should be also thoroughly substantiated. Its boundary with the Thanetian Stage seem to be insufficiently distinct. Assemblages of Selandian macro- and microfauna are inadequately studied, and paleobiogeographic environments essential for reliable stratigraphic correlation can be reconstructed with difficulties like in the case of the Montian Stage.

The problem of paleogeographic reconstructions for the Paleocene of Europe was mentioned long ago by Arkhangel'skii (1912). His followers, especially Pozaryska, Szczechura (Naidin and Ben'yamovskii, 1988, 1989) and Amitrov (1993), contributed much to understanding of the Paleocene paleobiogeographic realm in Europe. However, the more new data and concepts appear, the more problems and obstacles we meet. Thus, much should be done to elucidate the Paleocene paleobiogeography and biostratigraphic relations in the EPP.

At present, two evolutionary stages of the Paleocene physical-geographic environments in the northern EPP seas can be established. The **first stage** continues and terminates the Late Cretaceous carbonate cyclothem, and the **second** one corresponds to the succeeding terrigenous–siliceous cyclothem. On this base, it is natural to subdivide the Paleocene into the lower (early) and upper (late) subseries.

The lower Paleocene should include the Danian and Montian stages. As for the upper Paleocene, its subdivision into the Selandian and Thanetian stages should be taken as preliminary, especially with regard to the Selandian. In addition, the idea of Steurbaut (1998, pp. 143, 146) to subdivide the upper Paleocene into the Heersian and Landenian stages should not be forgotten.

CONCLUSION

In 1960–1970s, the Bakhchisarai stratotype section for the Paleogene was actively discussed in Russian scientific community and used in practice of geological mapping in corresponding areas (*Resheniya...*, 1963, pp. 146–147). This activity received the correct and reasonable criticism in many publications including that of Leonov *et al.* (1965).

However, we should agree with Menner (1983, p. 11), who stated that "it would be more useful not to criticize the Bakhchisarai sections," but "to characterize most fully the units recognized at the site" because "this continuous section of insignificant thickness exhibits almost all main Paleogene subdivisions, which can be traced in the moderate belt almost over the globe." Following this recommendation, we tried to demonstrate advantages of the Bakhchisarai reference section for solving the complicated stratigraphic problems of the Paleogene subdivisions considering the Paleocene as a good example.

It is also important that the standard should not be limited by the Bakhchisarai (Starosel'e–Suvlukaya) succession in the Churyuksu River valley. This succession should be supplemented with data on other successions exposed in the Kacha and Bel'bek river valleys of the southwestern Crimean Mountains (Fig. 8). Vyalov (1976, p. 81) understood the "Crimean section of the Paleogene" exactly in this sense, and then many significant features of the standard will not be given up, as it is inevitable when only one section (in fact, one outcrop), for instance, "the Bakhchisarai stratotype section of the Paleogene," is taken into consideration. The necessary stratigraphic features can be revealed **only by geological analysis of sufficiently large region, where complementary sections (outcrops) can be studied.**

ACKNOWLEDGMENTS

The work is supported by the Federal Program "Integratsiya" and the Russian Foundation for Basic Research, project no. 00-05-64917.

Reviewers Yu.B. Gladenkov and M.Ya. Serova

APPENDIX TO FIGS. 4 AND 5
LIST OF PALEONTOLOGICAL REMAINS
MACROFAUNA
Molluscs

Cephalopods: (1) *Hoploscaphites* gr. *constrictus* (Sowerby); (2) *Neobelemnella kazimiroviensis* (Skolozdrowna); (3) *Pachydiscus neubergicus* (Hauer); (4) *Pseudocenoceras warsanofievie* Shimansky; (5) *Teichertia similis* Shimansky.

Bivalves: (1) *Agerostrea lunata* (Nilsson); (2) *Artigesia krymica* (Bobkova); (3) *Chlamys (Microchlamys) acuteplicata* (Alth); (4) *C. orcina* Vassilenko; (5) *C. prestwichi* (Morris); (6) *Corbis montensis* Cossmann; (7) *C. transversaria* Cossmann; (8) *Cucullea volgensis* Barbot de Marni; (9) *Cyprina morrisi* Sowerby; (10) *Exogyra decussata* Goldfuss; (11) *Gryphaeostrea* gr. *eversa* (Melleville); (12) *Liostrea reussi* (Netschaew); (13) *Nemocardium edwardsi* Deshaes; (14) *Ostrea crimensis* Zubkovitsch; (15) *O. montensis* Cossmann; (16) *O. praemontensis* Gorbach; (17) *Phaladomya koninckii* Nyst; (18) *Pseudamosium corneum* (Sowerby); (19) *Pycnodonte antiqua* (Sowerby); (20) *P. beshkoshensis* (Weber); (21) *P. mirabilis* (Rousseau); (22) *P. similis* (Pusch); (23) *P. vesicularis* (Lamarck.).

Gastropods: (1) *Campanile korobkovi* Gorbach; (2) *Turritella kamyschinensis* Netschaew; (3) *T. montensis* Briart et Cornet.

Brachiopods: (1) *Cyclothyris magna* (Pettitt); (2) *Danocrania polonica* Rosenkrantz; (3) *D. tuberculata* (Nilsson); (4) *Terebratula* gr. *bisinuata* Lamarck; (5) *T. striata* Wahlenberg; (6) *Terebratulina tauremarginata* Sacco; (7) *T. woodi* Nyst.

Echinoderms: (1) *Bourgueticrinus danicus* Nielsen; (2) *Echinanthus* spp.; (3) *Echinocorys sulcata* Goldfuss; (4) *Tylocidaris rosenkrantzi* Brotzen.

MICROFAUNA
Foraminifers

Benthic forms: (1) *Alabamina midwayensis* Brotzen; (2) *Allomorphina* aff. *conica* Cushman et Todd; (3) *A.* aff. *cretaceae* Reuss; (4) *A.* cf. *halli* Jenning; (5) *Anomalinoides danicus* (Brotzen); (6) *A. fera* (Schutzkaja); (7) *A. simplex* Brotzen; (8) *Asterigerina bartoniana* (Ten Dam); (9) *Boldia* spp.; (10) *B. variabilis* Szczechura et Pozaryska; (11) *Bolivina deccurens* (Ehrenberg); (12) *Brotzenella acuta* (Plummer); (13) *Bulimina trigonalis* Ten Dam; (14) *Cibicides productus* (Terquem); (15) *C. reinholdi* Ten Dam; (16) *Cibicidoides alleni* (Plummer); (17) *C. commatus* (Morozova); (18) *C. cuvillieri* Rouvillos; (19) *C. howelli* (Toulmin); (20) *C.* gr. *ungerianus* (d'Orbigny); (21) *C. voltzianus* (d'Orbigny); (22) *C. succedens* (Brotzen); (23) *Elphidiella prima* (Ten Dam); (24) *Eponides saginaris* E. Bykova; (25) *E. toulmini* Brotzen; (26) *Falsoplanulina subbotinae* (Balakhmatova); (27) *Gavelinella lellingensis* Brotzen; (28) *Gavellinella* spp.; (29) *Globulina gibba* d'Orbigny; (30) *G. lacrima horrida* Reuss; (31) *G. rotundata* Borneman; (32) *Guttulina communis* d'Orbigny; (33) *G. hankeni* Cushman; (34) *G. problema* d'Orbigny; (35) *G.* gr. *problema* d'Orbigny; (36) *G. roemeri* Reuss; (37) *Gyroidina* gr. *octocamerata* Cushman et Hanna; (38) *Hanzawaia budensis* (van Vellen); (39) *H. ekblomi* (Brotzen); (40) *Heterolepa hemicompressus* (Morozova); (41) *H. libica* (Le Roy); (42) *H. propria* (Brotzen); (43) *Heterostomella gigantica* Subbotina; (44) *Karreria pallax* (Rzehak); (45) *Pararotalia saxorum* d'Orbigny; (46) *Pleurostomella paleocenica* Cushman; (47) *Protoelphidium sublaevae* (Ten Dam); (48) *Pullenia quinqueloba* (Reuss); (49) *Pirulina fusiformis* Roemer; (50) *Reussella minuta* Marsson; (51) *Robulus pseudovortex* Marsson; (52) *Ramulina globifera* Brady; (53) *Rotalia marginata* d'Orbigny; (54) *R. lithotamnia katschanenensis* Schutzkaja; (55) *R. saxorum* d'Orbigny; (56) *R. schutzkaja* Szczechura et Pozaryska; (57) *Rotorbinella mariei* (van Bellen); (58) *Rosalina* gr. *yestadiensis* Brotzen; (59) *Schlisserina astericus* (Gümlel); (60) *Sigmomorphina brotzeni* Pozaryska et Szczechura; (61) *S.* cf. *soluta* Brotzen; (62) *S.* gr. *soluta* Brotzen; (63) *Siphonina prima* Plummer; (64) *Stensioina beccariiformis* (White) (=*S. caucasica* Subbotina); (65) *Thalmannita pommeraniana* (Pozaryska et Szczechura); (66) *Uvigerina praecompacta* Balakhmatova; (67) *Vacuovalvulina kejzeri* (van Bellen); (68) *Vaginulinopsis eofragaria* Balakhmatova; (69) *Valvulineria ravni* Brotzen; (70) larger foraminifers (nummulites and discocyclins).

Planktonic forms: (71) *Acarinina acarinata* Subbotina; (72) *A. praecursoria* Morozova; (73) *A. soldadoensis* (Bronnimann); (74) *A. subsphaerica* Subbotina; (75) *A. triplex* Subbotina; (76) *Morozovella angulata* (White); (77) *M. subbotinae* (Morozova); (78) *Planorotalites elongata* (Glaessner); (79) *Pseudohastigerina* spp.; (80) *Subbotina aequiensis* Loeblich et Tappan; (81) *S. compressaeformis* Khalilov; (82) *S. nana* Khalilov; (83) *S. linaperta* Finlay; (84) *S. velascoensis* Cushman.

REFERENCES

Amitrov, O.V., *Istoriya gastropod palegenovykh morei zapada Evrazii* (Paleogene Gastropod Evolution in the Western Eurasia Seas), Moscow: Nauka, 1993.

Arkhangel'skii, A.D., Advances in Paleocene Studies in Russia from 1905 to 1911, *Ezhegod. Geol. Mineral. O–va Ros.*, 1912, vol. 14, issues 4–5, pp. 121–147.

Ashurov, A.A. and Nemkov, G.I., First Finds of Nummulites in the Crimean Danian Deposits, *Dokl. Akad. Nauk SSSR*, 1991, vol. 316, no. 2, pp. 464–467.

Aubry, M.-P., Northwestern European Paleogene Magnetostratigraphy, Biostratigraphy, and Paleogeography: Calcareous Nannofossil Evidence, *Geology*, 1985, vol. 13, no. 3, pp. 198–202.

Berggren, W.A., Some Planktonic Foraminifera from the Maastrichtian and Type Lanian Stages of Southern Scandinavia, *Stockh. Contrib. Geol.*, 1962, vol. 9, no. 1, pp. 1–106.

Berggren, W.A., Paleocene—a Micropaleontologist's Point of View, *Bull. Am. Ass. Petrol. Geol.*, 1965, vol. 49, no. 9, pp. 1473–1484.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., Cenozoic Geochronology, *Bull. Geol. Soc. Am.*, 1985, vol. 96, no. 11, pp. 1473–1484.

Berggren, W.A., Kent, D.V., Swisher, C.C., and Aubry, M.-P., A Revised Cenozoic Geochronology and Chronostratigraphy, *Special Publ. SEMP*, 1995, no. 54, pp. 129–212.

Bignot, G., The Position of the Montian Stage and Related Facies within the Stratigraphic-Palaeogeographic Framework of NW Europe during the Danian, *Contrib. Tert. Quat. Geol.*, 1993, vol. 29, nos. 3–4, pp. 47–59.

Brotzen, F., On *Tylocidaris* Species (Echinoidea) and the Stratigraphy of the Danian of Sweden, *Sveriges Geol. Unders, Ser. C*, 1959, no. 571, pp. 1–81.

Brotzen, F., The Swedish Paleocene and Its Foraminiferal Fauna, *Sveriges Geol. Unders, Ser. C*, 1948, no. 493, pp. 1–145.

Bykova, N.K., Gorbach, L.P., and Favorskaya, T.A., New Data on the Danian Stage of the Crimea, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1969, vol. 44, no. 6, p. 145.

Cavelier, C. and Pomerol, Ch., Stratigraphy of the Paleogene, *Bull. Soc. Geol. Fr., Ser. 8*, 1986, vol. 2, no. 2, pp. 255–265.

Davidzon, R.M., Kreidenkov, G.P., and Salibaev, G.Kh., *Stratigrafiya paleogenovykh otlozhenii Tadzhikskoi depressii i sopredel'nykh territorii* (Paleogene Stratigraphy of the Tajik Basin and Adjacent Areas), Dushanbe: Donish, 1952.

Gaudriaux, I. and Marliére, R., Relations entre Danien et Montien a Mons, *Bull. Soc. Geol. Fr., Ser. 7*, 1971, vol. 13, nos. 3–4, pp. 239–244.

Gohrbadt, K., Zur Gliedernuhg des Palëaogen im Helvetikum nördlich Salzburg nach plaktonischen Foraminiferen, *Mitt. Geol. Ges. Wien*, 1963, vol. 56, no. 1, pp. 1–116.

Gorbach, L.P., *Stratigrafiya i fauna mollyuskov rannego paleotsena Kryma* (Lower Paleocene Stratigraphy and Molluscan Fauna of the Crimea), Moscow: Nedra, 1972.

Gorbach, L.P. and Shekhotkin, V.V., Early Paleocene Calcareous Crust of the Crimean Mountains, *Dokl. Akad. Nauk SSSR*, 1982, no. 1, pp. 137–141.

Gorbach, L.P. and Zelinskaya, V.A., Stratigraphic Distribution of Brachiopods in the Upper Cretaceous and Lower Paleogene Deposits of the Crimea, *Tektonika i stratigrafiya* (Tectonics and Stratigraphy), Kiev, 1975, issue 9, pp. 67–71.

Gorbach, L.P., Favorskaya, T.A., and Schmidt, O.I., Spines of *Tylocidaris* from the Danian Deposits of the Crimea, in *Palentologicheskii zbornik* (Papers on Paleontology), Leningrad: Vses. Geol. Inst., 1974, issue 11, pp. 50–53.

Hansen, H.J., On the Biostratigraphic Age of the Lower Selandian of Denmark, *Bull. Geol. Soc. Denmark*, 1968, vol. 18, nos. 3–4, pp. 77–284.

Haq, B.U., Hardenbol, J., and Vail, P.R., Chronology of Fluctuating Sea Levels since the Triassic, *Science*, 1987, vol. 235, no. 4793, pp. 1156–1166.

Jenkins, D.G. and Luterbacher, H.P., Paleogene Stages and Their Boundaries (Introductory Remarks), *Neues Jahrb. Geol. Paläontol. Abh.*, 1992, vol. 186, nos. 1–2, pp. 1–5.

Kakhanova, L.P. and Yarkin, V.I., New Data on the Paleocene Deposits of Central Asia, *Dokl. Akad. Nauk SSSR*, 1966, vol. 167, no. 6, pp. 1334–1357.

Korde, K.B., Hydroconozoa from the Cretaceous and Paleogene Deposits of the Crimea, in *Razvitie i smena organicheskogo mira na rubezhe mezozoya i kainozoya* (Organic Evolution and Changes at the Mesozoic–Cenozoic Boundary), Moscow: Nauka, 1975, pp. 32–38.

Krach, W., Fauna i Stratigrafia Paleocenu Srudkowej Sisly, *Studia Geol. Polon.*, 1981, vol. 71, pp. 5–80.

Lange, O.K. and Mirchink, G.F., On Upper Cretaceous and Tertiary Deposits of the Bakhchisarai Area, *Byull. Mosk. O–va Ispyt. Prir.*, 1909 (1910), vol. 23, pp. 36–42.

Leonov, G.P., Alimarina, V.P., and Naidin, D.P., Principle and Methods of Recognizing Stages of the Standard Scale, *Vestn. Mosk. Univ., Ser. Geol.*, 1965, no. 4, pp. 15–28.

Makarenko, D.E., *Mollyuski paleotsenovykh otlozhenii Kryma* (Paleocene Mollusks of the Crimea), Kiev: Akad. Nauk USSR, 1961.

Marliére, R., Le Montien de Mons: etat de la question. Colloque sur le Paleogene (Bordeaux, 1962), *Mem. BRGM*, 1964, no. 28, pp. 875–884.

Marliére, R., Sur le stratotype du Montien a Mons, *Mem. Expl. Cartes Geol. Min. Belg.*, 1977, vol. 17, no. 1, pp. 1–230.

Maslakova, N.I. and Nguen van Ngok, Distribution of Benthic Foraminifers in the Cretaceous–Paleogene Boundary Deposits of the Southwestern Crimea, in *Razvitie i smena organicheskogo mira na rubezhe mezozoya i kainozoya* (Organic Evolution and Changes at the Mesozoic–Cenozoic Boundary), Moscow: Nauka, 1975, pp. 7–14.

Menner, V.V., Paleogene Stages Exemplified by the Bakhchisarai Section of the Crimea, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1983, no. 11, pp. 5–11.

Moorkens, T.L., Foraminifera of the Montian Stratotype, and of Subjacent Strata in the "Mons Well 1996," with a Review of Belgian Paleocene Stratigraphy, *Mem. Expl. Cartes Geol. Min. Belg.*, 1982, vol. 17, no. 2, pp. 1–186.

Moorkens, T.L., Late Paleocene to Early Eocene Bio-Sequence- and Volcanic Event Stratigraphy: Correlation of Belgium and North Sea Basin, *Strata, Ser. 1*, 1998, vol. 9, pp. 101–105.

Moroz, S.A. and Savron', E.B., *Kainozoiskie morya Donbassa* (The Cenozoic Seas of the Donetsk Coal Basin), Kiev: Kiev. Univ., 1975.

Morozova, V.G., The Danian–Montian Zonation of the USSR and the Cretaceous–Paleogene Boundary, in *Mezhdunarodnyi geologicheskii kongress. XXI sessiya. Doklady sovetskikh geologov. Problema 5* (XXI Int. Geol. Congress. Repts of Sov. Geol. Problem 5), Moscow: Akad. Nauk SSSR, 1960, pp. 83–100.

Moskvin, M.M., *Pseudogibbaster* is a New Genus of Danian and Paleocene Echinoids, *Paleontol. Zh.*, 1983, no. 3, pp. 112–116.

Moskvin, M.M. and Naidin, D.P., The Danian and Contiguous Deposits of the Crimea, Caucasus, Caspian Area, and Southeastern Russian Platform, in *Mezhdunarodnyi geologicheskii kongress. XXI sessiya. Doklady sovetskikh geologov. Problema 5* (XXI Int. Geol. Congress. Repts of Sov. Geol. Problem 5), Moscow: Akad. Nauk SSSR, 1960, pp. 15–40.

Muratov, M.V., Tectonics and Evolution of the Alpine Geosynclinal Area of the Southern Part of the European USSR and Adjacent Countries, in *Tektonika SSSR* (The Tectonics of the USSR), Moscow: Akad. Nauk SSSR, 1949, vol. 2.

Naidin, D.P., The Danian and Montian Stratotypes, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1960, vol. 35, no. 5, pp. 97–106.

Naidin, D.P., The Danian and Montian Deposits of the Crimea, in *Sbornik v chest' akad. I. Ivcheva* (Collection of

Papers in Honor of Academician I. Ivchev), Sofiya. Akad. Nauk Bulg., 1964, pp. 164–184.

Naidin, D.P., The Cretaceous–Paleogene Boundary Problem in Recent Literature, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1972, vol. 47, no. 3, pp. 53–67.

Naidin, D.P. and Ben'yamovskii, V.N., On the Upper Limit of the Danian Stage. Arcticle 1: The Paleocene Stage Stratotypes, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1988, no. 10, pp. 3–15.

Naidin, D.P. and Ben'yamovskii, V.N., On the Upper Limit of the Danian Stage. Arcticle 2: The Danian, Montian, and Selandian outside the Stratotype Areas, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1989, no. 1, pp. 21–37.

Naidin, D.P. and Ben'yamovskii, V.N., The Suvlukaya Paleogene Section (the Crimea), *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 3, pp. 75–86.

Naidin, D.P., Ben'yamovskii, V.N., and Kopaevich, L.F., Paleogene Reference Sections of Mangyshlak, *Stratigr. Geol. Korrelyatsiya*, 1996, vol. 4, no. 3, pp. 46–61.

Panteleev, G.S., *Stratigrafiya i dvustvorchatye mollyuski datskikh i paletsenovykh otlozhenii Zakaspiya* (The Danian–Paleocene Stratigraphy and Bivalve Mollusks of the Caspian Area), Moscow: Nauka, 1974.

Perch-Nielsen, K. and Hansen, J.M., Selandian, *Mem. Hors. Ser. 2, Bull. Inf. Geol. Basin Paris*, 1981, pp. 219–230.

Pomerol, Ch., Stratigraphy of Paleogene: Hiatuses and Transitions, *Proc. Geol. Assoc. London*, 1989, vol. 100, pt. 3, pp. 313–324.

Poslavskaya, N.A. and Moskvin, M.M., Echinoderms, in *Atlas verkhnemelovoi fauny Severnogo Kavkaza i Kryma* (Atlas of the Late Cretaceous Fauna of the Northern Caucasus and the Crimea), Moscow: Gostoptekhizdat, 1959, pp. 237–304.

Poslavskaya, N.A. and Moskvin, M.M., Echinoids of the Order Spotangoida in the Danian and Contiguous Deposits of the Crimea, Caucasus and Caspian Area, in *Mezhdunarodnyi geologicheskii kongress. XXI sessiya. Doklady sovetskikh geologov. Problema 5* (XXI Int. Geol. Congress. Repts of Sov. Geol. Problem 5), Moscow: Akad. Nauk SSSR, 1960, pp. 47–82.

Pozaryska, K. and Szczechura, J., Foraminifera from the Paleocene of Poland, Their Ecological and Biostratigraphical Meaning, *Palaeontol. Polon.*, 1968, no. 20, pp. 1–107.

Pozaryska, K. and Szczechura, J., On Some Warm-Water Foraminifers from the Polish Montian, *Acta Palaeontol. Polon.*, 1970, vol. 15, no. 1, pp. 95–108.

Prendel, R.A., Geological Review of the Cretaceous Deposits and Cretaceous-Eocene Boundary Beds of the Crimea, *Zap. Novorossiisk. O–va Estestvoispyt.*, 1876, vol. 4, no. 1, pp. 67–102.

Putevoditel' ekskursii XII Evropeiskii mikropaleontologicheskii kollokvium (Excursion Guidebook of XII Europ. Micropaleontol. Colloq.), Moscow: Mosk. Gos. Univ., 1971, Part 1.

Resolution of the Permanent Commission on Paleogene Stratigraphy of the Interdepartmental Stratigraphic Committee of the USSR, 1962, *Sov. Geol.*, 1963, no. 4, pp. 145–154.

Resolution of XV Plenary Session of the Commission on Paleogene Stratigraphy, 1981, in *Postanovleniya MSK i ego postoyannykh komissii* (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), 1983, issue 21, pp. 41–44.

Resolution of XVI Plenary Session of the Commission on Paleogene Stratigraphy, in *Postanovleniya MSK i ego postoyannykh komissii* (Resolutions of the Interdepartmental Stratigraphic Committee and Its Permanent Commissions), 1989, issue. 24, pp. 51–54.

Robaszynski, F., Montian, in *Stratotypes of Paleogene Stages*, Pomerol, Ch., Ed., Paris, 1981, pp. 181–200.

Robaszynski, F., Paleocene et Eocene inferieur de la Region de Mons et du Nord de La France: Arguments actuals de correlation, *Bull. Soc. Belge Geol.*, 1979, vol. 87, no. 4, pp. 239–247.

Rosenkrantz, A., Note on Some *Crania* from Central Poland, *Acta Palaeontol. Polon.*, 1964, vol. 9, no. 4, pp. 513–538.

Salaj, J., *Micrbiostratigraphie du Cretace et du Paleogene de la Tunisie septentrionale et orientale (Hypostratotypes tunisiens)*, Bratislava: Inst. Geol. de D. *Stur*, 1980.

Stukenberg, A.A., Geological Review of the Crimea, in *Materialy dlya geologii Rossii* (Materials on the Russian Geology), 1873, vol. 5, pp. 1–100.

Shutskaya, E.K., Foraminifers of the Upper Beds of the "Danian-Montian" Limestones of the Southwestern Crimea, *Tr. Vses. Nauchn. Issled. Geol. Neft. Inst.*, 1958, no. 9, pp. 197–211.

Shutskaya, E.K., Late Paleocene Foraminifers of the Western Crimea (the Bakhchisarai Area, *Tr. Vses. Nauchn. Issled. Geol. Neft. Inst.*, 1960, no. 16, pp. 235–259.

Shutskaya, E.K., The Lower Paleogene Stratigraphy, Foraminifers and Paleogeography of the Crimean, Ciscaucasia, and the Western Central Asia, *Tr. Vses. Nauchn. Issled. Geol. Neft. Inst.*, 1970, no. 70, pp. 1–255.

Steurbaut, E., High-Resolution Holostratigraphy of Middle Paleocene to Early Eocene Strata in Belgium and Adjacent Areas, *Palaontographica, Abh. A*, 1998, vol. 247, nos. 5–6, pp. 91–156.

Szczechura, J. and Pozaryska, K., The Montian Warm-Water Foraminifers in the Meridional Province of Europe, *Acta Palaeontol. Polon.*, 1971, vol. 16, no. 4, pp. 345–368.

Titova, M.V. and Favorskaya, T.A., The Danian *Crania* of the Crimea, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1983, vol. 58, no. 4, pp. 101–113.

Troelsen, J.C., Some Planktonic Foraminifera of the Type Lanian and Their Stratigraphic Importance, *Bull. US Natur. Mus.*, 1957, no. 215, pp. 125–134.

Vincent, E., Observations sur les couchex montiennes traiversees au Puits no. 2 du charbonnage d'Eyesden, pres de Maaseyck (Limbourg), *Bull. Acad. R. Belg. Sci., Ser. 5*, 1928, vol. 14, no. 10, pp. 554–568.

Vyalov, O.S., The Bakhchisarai Section of the Paleogene. The Main Paleocene Outcrops, in *Geologiya i geokhimiya goryuchikh iskopaemykh* (Geology and Geochemistry of Fuel Minerals), 1976, issue 47, pp. 1–145.

Vyalov, O.S. and Gorbach, L.P., Significance of Late Cretaceous and Paleogene Oysters for Stratigraphy and Interregional Correlations (the Crimea as an Example), *Trudy 24 sessii Vsesoyuznogo paleontologicheskogo obshchestva*, (Proc. 24th Conf. All-Union Paleontol. Soc., 1978), Leningrad, 1982, pp. 98–103.

Yartseva, M.V., On the Age of the "Danian–Montian" Limestones of the Southwestern Crimea, *Vopr. Mikropaleontol.*, 1966, no. 10, pp. 248–254.

Yartseva, M.V., Assemblages of Benthic Foraminifers from the Danian and Paleocene Stratotypes of the Bakhchisarai Area, *Tektonika i Stratigrafiya* (Tectonics and Stratigraphy), 1973, issue. 6, pp. 33–39.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 396–404. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 84–92.
Original Russian Text Copyright © 2000 by Chumakov.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

The Problem of the Miocene–Pliocene Boundary in the Euxinian Region

I. S. Chumakov†

Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

Received October 18, 1998

Abstract—Application of micropaleontological (nannoplankton) and paleomagnetic methods for stratigraphic subdivision and correlation of Upper Neogene stratigraphic units in the regional scale of the Euxinian region (the Black Sea areas of the Eastern Paratethys) and, what is more important, for defining the Miocene–Pliocene boundary in this region in accordance with the global (Mediterranean) scale resulted in substantial discrepancies between age estimates of local stages, substages, and beds. For instance, different authors define the Miocene–Pliocene boundary within a very wide time interval (more than 4 m.y.). The paper considers both the objective and subjective causes of these discrepancies and demonstrates the interconnection between geological events that occurred in the Mediterranean and Euxinian regions during the terminal Miocene–initial Pliocene. Contrary to concepts of other researchers, the boundary between the Pontian and Kimmerian regional stages in the Euxinian region is considered as representing the age and event analogue of the Miocene–Pliocene boundary that is defined in the Mediterranean as corresponding to the boundary between Messinian and Zanclean stages. Sea-level fluctuations in the Euxinian (Black Sea, Sea of Azov, and Dacian) basins at the end of the Pontian and in the Kimmerian ages reflect changes in the hydrological regime in the Mediterranean Sea and World Ocean.

Key words: *stratigraphy, paleomagnetism, correlation, Pontian, Kimmerian, Zanclean, Messinian, Euxinian region, Mediterranean region.*

The direct correlation of geological events that occurred in the Mediterranean (Tethys) and Eastern Paratethys during the terminal Miocene–initial Pliocene is impossible, because the regional stratigraphic scale for the latter region is based on evolutionary succession of the endemic malakofauna. This problem can be solved by applying both the micropaleontological and physical methods of stratigraphy. Nonetheless, as will be shown below, these methods (nannoplankton studies and paleomagnetic measurements) led different authors to dissimilar conclusions concerning correlation of the Upper Neogene stages, substages, and beds of the Eastern Paratethys with the global (Mediterranean) scale and the Miocene–Pliocene boundary position in the Eastern Paratethys proper. Nevertheless, it seems that the available inconsistencies can be overcome using the recent data including those obtained by deep-sea drilling in the oceans.

The discovery and study of the calcareous nannoplankton in the Eastern Paratethys, which was thought to be inadaptable to existence in brackish-water basins, provided the new approach to stratigraphy, paleontology, and paleogeography of the Eastern Paratethys, implying as well that two biotas (endemic and oceanic) coexisted there. The discovery distinctly indicates connection between Tethys and Paratethys and penetration of Mediterranean waters with the relevant microfauna and microflora into the latter basin similarly to their penetration into the Black Sea nowadays.

The main contribution to these studies was that of V.N. Semenenko (malacofauna) and S.A. Lyul'eva (nannoplankton), who published several papers demonstrating new proxies in investigation of the Late Neogene history of the Eastern Paratethys. Interpretation of paleontological results of these researchers requires, however, some corrections and consideration of new data. For instance, at the initial stage of the nannoplankton studies in the Kerch'–Taman' region, Semenenko (1987, p. 205) arrived at the conclusion that "the Miocene–Pliocene boundary should coincide with the base of the Kamyshburun Horizon within the Kimmerian Stage of the Eastern Paratethys, because the Azov Horizon of the stage is referred on the basis of found *Discoaster quinqueramus* and *Ceratolithus tricorniculatus* to the paleomagnetic Chron 5, whereas the overlying Kimmerian sequence contains *Ceratolithus acutus* and corresponds to the Gilbert polarity zone, i.e., to the Pliocene.

Semenenko and Teslenko (1994, p. 58), who reconsidered the same problem, were quite confident to state the following: "We were first to establish that the global Miocene–Pliocene boundary about 5 Ma old is in oce-

† Deceased.

anic and Mediterranean (Eastern Paratethys) sedimentary sequences above the Pontian somewhere between this stage and middle Kimmerian," i.e., inside the Azov Beds. It should be noted that the concept, according to which the occurrence of *D. quinqueramus* below the Miocene–Pliocene boundary in the standard stratigraphic scale and of *C. acutus* above this level, was popular in the period, when Semenenko and Lyul'eva studied Kimmerian nannoplankton, and led these authors to the above-mentioned conclusion. The study of cores from deep-sea drilling sites showed that *D. quinqueramus* became extinct in the Early Pliocene, and this fact allowed Berggren *et al.*, (1995), when defining the Miocene–Pliocene boundary, to place the LAD of *D. quinqueramus* and FAD of *C. acutus* above this boundary.[1] Judging from the quoted publication, this conclusion is made based on the data from ODP Holes 845 and 854. Consequently, the occurrence of *Discoaster quinqueramus* in the Azov Beds cannot serve as an evidence that their lower part corresponds to the Upper Miocene (Messinian) and, thus, as the basis for placing the Miocene–Pliocene boundary inside the Azov Beds of the Kimmerian.

To confirm the correctness of defining the Miocene–Pliocene boundary in the Eastern Paratethys (in fact only in the Euxinian region), Semenenko leans upon the results of magnetostratigraphic study by M.A. Pevzner, who investigated core samples from Borehole 15 drilled in the Kerch' Peninsula and partly the rock sequence in the Taman' Peninsula.

In the magnetochronological scale by Pevzner (1976, p. 18), the Kimmerian Stage corresponds to the Gilbert Chronozone and Chron 5 (in their complete range), and also to the upper part of Chron 6. The Azov Beds (lower Kimmerian) are referred here to the lower half of the Gilbert Chronozone (probably at the level close to the Nunivak Subchron) coupled with Chrons 5 and 6. Inasmuch as the upper boundary of the Azov Beds was determined by Pevzner as corresponding to the level of "about 4.4 Ma (between the Sidufjall and Nunivak polarity subchronozones," the total duration of the Azov time is estimated to be 1.7–1.8 m.y. Nonetheless, when analyzing some works by Pevzner (1976, 1986) and information presented in articles and monograph by Semenenko (1978, 1979, 1987), I should note that they lack data that would allow the magnetic polarity Chrons 5 and 6, as well as particular events within the Gilbert Chronozone, to be established in the study sections.

According to Semenenko (1987, pp. 144, 159), "the lower part of the Kimmerian section in Borehole 15 is not studied because it is composed of sands unsuitable for paleomagnetic measurements." Further he states: "In the Borehole 15 section, Chron 5 is not registered. It corresponds to the hiatus."

It should be noted that the Borehole 15 drilled in the Chegerchin syncline of the Kerch' Peninsula and used as the basis for all stratigraphic interpretations by Semenenko and Lyul'eva shows the first occurrence of the Kimmerian nannoplankton at the level located 12 m above the Pontian–Kimmerian boundary. Specimens of *D. quinqueramus* are registered in the overlying 14-m-thick interval. It follows that the Thvera Polarity Subzone can not be found below the level of 26 m above the Pontian–Kimmerian boundary. However, first paleomagnetic measurements were carried out only 37 m above this boundary. Thus, the Thvera Subchronozone that is very important for stratigraphic interpretations either was missed or corresponds to the paleomagnetic event recorded in the interval of 44–54 m above the Pontian–Kimmerian boundary. However, even if we accept the last version, all five recorded events of normal polarity cannot be included into the Gilbert Chronozone, which comprises, according to the cited authors, the most of the Kimmerian section and includes only four events of this kind. The "extra events" (one or two?) should be referred to the Gauss Chronozone, as is shown in works by Zubakov and Kochegura (1976, 1990). By the way, summarizing his data on the Kimmerian, Pevzner (1986, p. 14) notes: "The exact number of normal polarity zones in the reversibly magnetized Kimmerian sequences and their correlation with the Gilbert magnetic events is still an open question."

In the section of the Zheleznyi Rog Cape, "the Azov Horizon is normally magnetized and correlated with Chron 5," according to Semenenko and Lyul'eva (1982, pp. 65, 66), though Pevzner placed it in the interval of reversed magnetization. However, mentioning the find of *Ceratolithus* ex gr. *acutus* (in Lyul'eva, 1989, the species lacks the addition "ex gr.") in the same work, authors indicate its occurrence level in the section as "*the base of the lower Kimmerian*" (emphasis is mine, **I.Ch.**), and, consequently, Chron 5 cannot be in the lower part of the Kimmerian, because *C. acutus* occurs only in sediments of the Gilbert Chronozone.

As it follows from the article by Semenenko (1987, pp. 144–146, 159), "in the Zheleznyi Rog section, the uppermost part of Chron 5 corresponds to normally magnetized Kimmerian deposits," although he states further that both the Pontian clay beds "and basal layers of overlying lower Kimmerian sediments (below the ore bed about 3.5 m thick) are reversely magnetized in this section. The overlying 12-m-thick sequence is characterized by the normal polarity." Thus, the lowermost Kimmerian interval of normal magnetization is established in this section only above the Kamyshburun (middle Kimmerian) beds and, consequently, the Azov Beds cannot be referred in this case to the Cronozone 5.

[1] To avoid potential confusions, I cite the original conclusion by Berggren *et al.*: "The Miocene/Pliocene boundary is equated with the base of the Zanclean Stage as stratotypified at Capo Rosello in Sicily (Cita, 1975; Hilgen and Langereis, 1993; Langereis and Hilgen, 1991; Hilgen, 1991) which appears to be bracketed by the FADs of *Gt. tumida* and *Gt. sphericomiozea* (below) and the FADs of *Ceratolithus acutus* and *Gt. puncticulata* and LAD of *Discoaster quinqueramus* (above)" (p. 199).

In addition, it should be noted that the whole Kimmerian in the Zheleznyi Rog section (from its base to the roof of the Kamyshburun Beds) is shown in the work by Semenenko and Pevzner (1979, Fig. 2) as the interval unstudied.

All above-mentioned data allow the conclusion that neither micropaleontological nor paleomagnetic data substantiate the Miocene–Pliocene boundary position within the Azov Beds.

While analyzing the results of paleomagnetic studies in the Taman' Peninsula, Zubakov (1990, Fig. 5, 1-3) correlated the Azov Beds with the Gilbert Chronozone in its interval from the lower part of the Cochiti Subchronozone to the upper part of the Thvera Subchronozone. Thus, this author places the Kimmerian–Pontian boundary within the latter.

When defining the Miocene–Pliocene boundary, Zubakov (1990, p. 76) proceeds, as he writes, from the "domestic tradition" to refer the Pontian to the Pliocene. As a result, "... the Miocene–Pliocene boundary in Russia is dated back to either 6.8 or 5.5 Ma."

An attempt of V.M. Trubikhin (see in Gurarii *et al.*, 1995) to define the Miocene–Pliocene boundary and to correlate regional stages of the Eastern Paratethys with the Mediterranean (standard) scale should be considered as unfortunate. Paleomagnetic measurements performed in continental terrigenous sediments of Georgia are not coordinated with paleontological data, and mentioned researchers did not take into consideration probable abundant hiatuses (sand and sandstone beds). In addition, the presented correlation schemes ignore available and abundant radiological dates, as well as previous micropaleontological data.[2] The considered article completely ignores the results of paleomagnetic measurements performed in the Transcaucasia by Tret'yak *et al.* (1990) in the same stratigraphic interval. As a result, discovering in the barren sequence the incomplete Pontian and, partly, Maeotian intervals, Gurarii *et al.* (1995, p. 71) arrived at the conclusion that "... the Maeotian corresponds to Chronozones 5 and 6, whereas the Pontian, the Azov Beds included, is an analogue of the lower part of the Gilbert Chronozone including the Thvera Subchronozone, i.e., the entire interval is correlative with the Messinian." Finally, they state: "... the Messinian (s. l.) is characterized in the magnetochronological scale by the range and position approximately similar to those of the Maeotian–Pontian of the Paratethys," thus excluding the Azov Beds. Eventually, It was proposed to place the Miocene–Pliocene boundary under the Messinian or Maeotian respectively.

[2] To make themselves free in this aspect, the authors stated that "... neither molluscan fauna nor plankton or fission-track dating provide, unfortunately, sufficiently reliable age estimates" (Gurarii *et al.*, 1995, p. 71). According to the cited work, most reliable reference points for stratigraphic subdivision and correlation are vertebrate fossils in continental sequences.

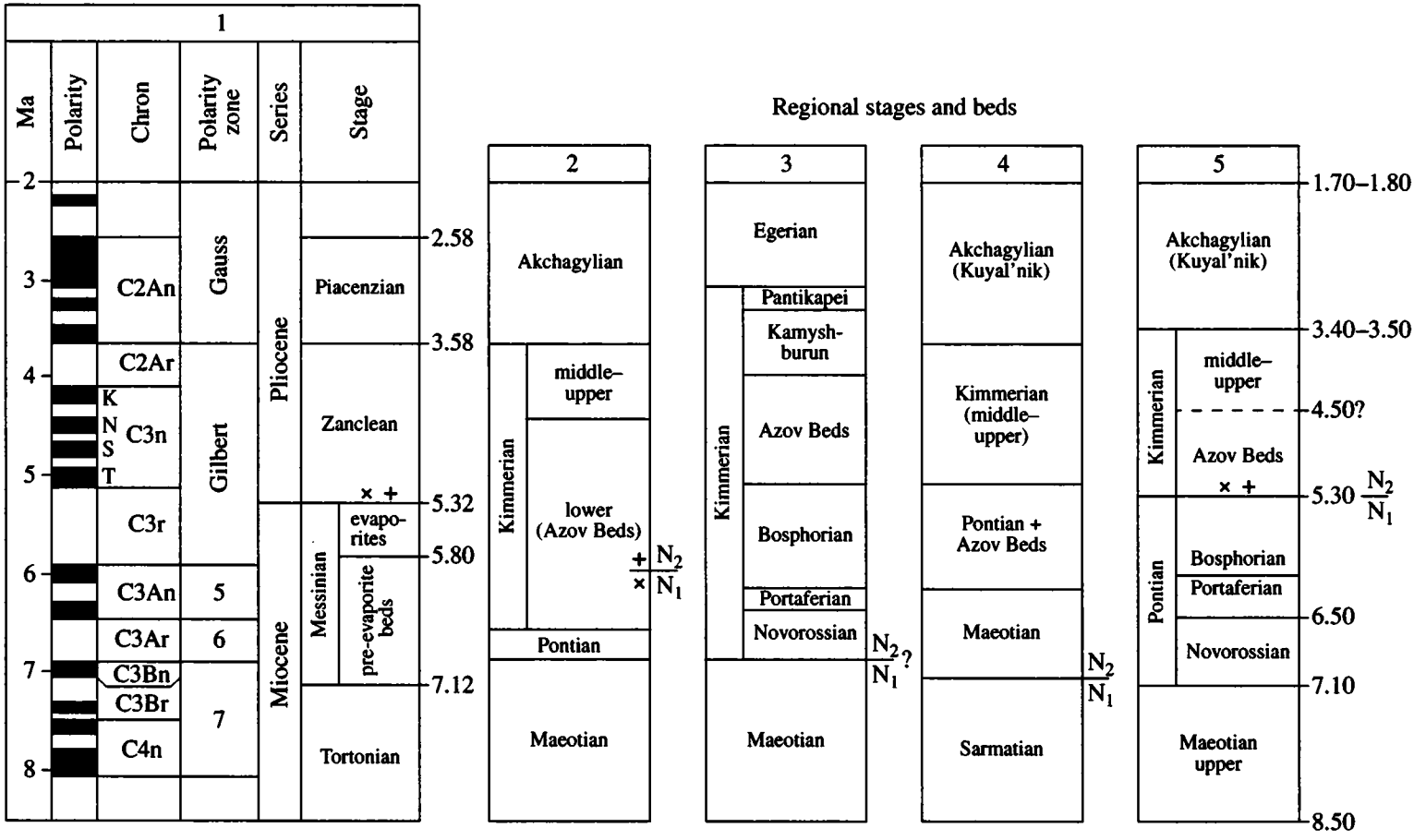
As follows from the paleomagnetic scale by Trubikhin (*Neogene Stratigraphy...*, 1996), the integral duration of the Pontian regional stage and Azov Beds is 1 m.y. (the time span comparable with that of the Azov Beds only as estimated by Pevzner).

The above-mentioned data characterize different approaches to interpretation of paleomagnetic measurements performed by different researchers and, consequently, to the position of the Miocene–Pliocene boundary and correlation of stratigraphic units within the wider stratigraphic interval. As a result, Pevzner and Semenenko place the Miocene–Pliocene boundary within the middle (upper?) part of the Azov Beds, Zubakov correlates the latter with the Maeotian–Pontian boundary, and Trubikhin draws it "under the Maeotian." The corresponding difference in age estimates of the Miocene–Pliocene boundary approximates 4.5 m.y. (see figure).

One important point should be emphasized here. It was noted previously (Chumakov *et al.*, 1982) that Pevzner established Chronozone 5 only in continental sequences beyond the Eastern Paratethys. Zubakov (1990) assumes the presence of Chronozone 5, correlating it with the Portaferian, also in continental sediments of the Lyubimovka section in the Crimea. According to him, a significant portion of the upper Pontian, as well as the most part of the Kimmerian, correspond to the Gilbert Chronozone, but not to Chronozone 5. Trubikhin registers equivalents of Chronozone 5 within continental deposits of Georgia, erroneously referring to this unit the basal Pontian layers and the upper Maeotian. The question arises as to whether there is the Magnetic Polarity Zone 5 in marine sequences of the Euxinian region? This problem is to be considered in a special paper.

In the monograph summarizing to some extent the results of his investigations, Semenenko (1987, p. 180) comments events that occurred in the Euxinian region at the Pontian–Kimmerian boundary in the following way: "The Pontian–Kimmerian boundary is marked by obvious erosion signs probably coeval with the erosion phase confined to the Messinian–Zanclean (in other words, the Miocene–Pliocene) boundary in the Mediterranean Sea. The onset of new transgression corresponds to the beginning of the Kimmerian Age. It coincides with the beginning of the second stage of the Messinian basin evolution." What a contradicting conclusion!

According to Semenenko (1987, p. 180), the earliest Kimmerian (the Azov time) transgression coincides with the accumulation period of Messinian evaporites. "On the other hand, climatic transgression was coeval with the Zanclean one, which fact explains penetration of nannoplankton into the Kimmerian basin." Thus, the Kimmerian Age was marked, in opinion of Semenenko, by two transgression: the first one occurred at the beginning of the Kimmerian (Late Miocene) and the second (Zanclean, climatic) in the initial Pliocene.



Magnetostratigraphic correlation of the Upper Miocene and Pliocene regional stages of the Euxinian region with the standard scale: (1) standard scale (Berggren *et al.*, 1995); (2–4) regional scales for the Euxinian basins after: (2) Pevzner (1986) and Semenenko and Pevzner (1979), (3) Zubakov (1990), (4) Trubikhin (Gurarii *et al.*, 1995; *Neogene Stratigraphy...*, 1996); (5) radiological scale after Chumakov (1993) with modifications; (C) Cochiti, (N) Nunivak, (S) Sidufial, and (T) Thvera normal-polarity subzones in the Gilbert Polarity Zone; occurrence levels of *Discoaster quinqueramus* (x) and *Ceratolithus acutus* (+).

Simultaneously, the erosion phase at the Pontian–Kimmerian boundary corresponds in his interpretation to the similar phase at the Messinian–Zanclean boundary. It is clear that the author intends to correlate all events, on the one hand, with occurrence levels of nannofossils in the Kimmerian sequence, and on the other, with events that occurred in the Mediterranean Sea at the Miocene–Pliocene boundary. Inasmuch as *Discoaster quinqueramus* occurs in the Pliocene, it should be noted that such a complicated interpretation becomes superfluous. Nonetheless later, Semenenko and Teslenko (1994) write about the late Pontian–early Kimmerian regression, to which they relate the overdeepening of old and formation of new river valleys explaining this phenomenon by the lowered erosion base. Getting acquainted with several Semenenko's articles, I found unclear his concept of the Azov basin history.

In my opinion, taking into consideration all geological and paleontological data, the early Kimmerian regression has never happened, because penetration of nannoplankton assemblage with *D. quinqueramus, C. tricorniculatus, C. acutus*, and other species into the Euxinian basin, its Azov part included, could take place only under condition of the early Pliocene (Zanclean) transgression.

The opening of the Gibraltar Passage resulted in flooding of constituting depressions and separating bridges of the Mediterranean Sea. It should be noted that brackish-water basins of the lago-mare type appeared in the deepest parts of the sea by that moment to quickly replace the evaporite basin stage of the Messinian evolution. The early Pliocene (Zanclean) transgression in the Mediterranean region was related to leveling of the World Ocean and desiccated Mediterranean Sea, i.e., it was eustatic. The leveling turned the Mediterranean Sea into the deep basin and also affected the entire Euxinian basin (including the Azov and Dacian subbasins) promoting prochoresis of oceanic nannoplankton.[3] However, conditions favorable for migration of marine organisms into the Euxinian basin also appeared in the course of the subsequent eustatic transgression (the second Zanclean one) against the background of the first Pliocene climatic optimum, when sea level raised, according to different estimates, by 30–40 m owing to the Antarctic ice thawing and reduction of the northern cryosphere. In general, the onset of this transgression corresponds to the Sidufial Subchronozone (4.8 Ma).[4] *D. quinqueramus* from the basal Azov Beds, whose extinction occurred directly prior to the Thvera Subchronozone (although above the Miocene–Pliocene boundary), implies penetration of the oceanic nannoflora in the Azov basin at the very beginning of the Zanclean.

Similarly to the first Zanclean "leveling transgression" in the Mediterranean Sea, the early Kimmerian transgression in the Euxinian basin was instant in geological terms (Chumakov, 1974). That is why sections of the Azov Beds in areas lacking local river deltas begin with clays, though having a distinct contact with the Pontian layers. The completely similar contact of Zanclean sediments with underlying rocks different in age can be frequently observed in many Mediterranean areas.[5]

Noting the fact of the Kimmerian transgression in the Euxinian basin, Muratov (1951, p. 19) wrote that "in the Kerch' Peninsula, the Kimmerian sediments sometimes fill deep erosion depressions in the ingressive mode and rest, with distinct erosion marks, upon the Pontian, Miocene, and, even, Maikop clays." Two stages can be defined in the phenomenon noted by Muratov. The first stage of the Zanclean transgression that leveled basin surfaces indeed gave rise to ingression into all erosional and tectonic depressions without visible signs of erosion. The second stage related to global transgression caused overlapping of different older deposits with the Kimmerian layers, as was noted by Muratov. In addition, the considered contact is locally marked by the low-angle unconformity between the Kamyshburun Beds and older rocks.

It is interesting that in all known sections of the Pontian shallow-water facies, the upper Pontian (Bosphorian) Substage is either missing or partly eroded, the middle (Portaferian) substage is frequently absent, and the Kimmerian sometimes begins directly with the ore (Kamyshburun) beds. For instance, the Pontian lectostratotype (Odessa locality) includes only the lower (Novorossian) substage, also partly eroded, whereas its hypostratotype (the Kamyshburun profile near Kerch') lacks the Azov Beds of the Kimmerian, although shallow-water facies are typical of all three Pontian substages. It is clear that the upper layers of the Bosphorian Substage are also eroded there. Apparently, large areas beyond depressions of the northern Black Sea region, the Kamyshburun area included, remained above sea level in the Azov time and only after a sharp sea-level rise during the global Pliocene transgression turned into shallow-water well-heated basins favorable for development of gigantic molluscan forms.

In my opinion (Chumakov *et al.*, 1982; Chumakov, 1993), the Pontian Age terminated with regression in response to a partial discharge of water from the Pon-

[3] According to the data by Lyul'eva (1991), the nannofossil assemblage in the lower (Gethian) layers of the Pliocene section in the Dacian basin is more diverse that that in the Kerch' and Taman' areas that seems quite natural, when the relative proximity of Romania to the Mediterranean Sea is taken into consideration.

[4] According to the data of Australian researchers (Anderson, 1980), the sea-level rise estimated for the interval of 4.5 to 3.5 Ma was 75 m.

[5] In buried canyons of the Mediterranean, the Zanclean clays are underlain by sands and pebbly deposits referred by French geologists, "in line with tradition," to the Infra-Pliocene, but this standpoint is incorrect because these deposits represent alluvial sediments of the Messinian time. Similarly, sands and sandstones locally underlying the Pontian and Kimmerian deposits, are considered, without reliable substantiation, as representing the basal strata of the latter.

tian basin into the Mediterranean Sea, which turned into the brackish-water (to 12–15%) lago-mare basin with molluscan and ostracod fauna of the Pontian appearance. The new sea level position in the Pontian basin was controlled by the sill separating it from the Mediterranean Sea. The basin remained to be the site of continuing sedimentation and the habitat of Pontian malacofauna or, most likely, of its forms adapted to brackish-water conditions. I proposed to term this period, which was not recorded in terrestrial sequences, as the Epi-Pontian. Indeed, the sharp sea level fall in the Pontian marine basin is recorded in the overdeepening of local river valleys, erosion of Pontian deposits over large areas, and also in formation of karst, buried soil, weathering crusts, limestone recrystallization crusts, and in accumulation of red sandstones and clays. Semenenko and Teslenko (1994, p. 65) also note that "during the period of the maximum Pontian regression, the modern area of deep Black Sea basin was occupied for a short time by land with several almost freshwater basins," and that "formation of the deep Black Sea basin began" only in the Kimmerian. The question is to what stage should be referred sediments of the almost freshwater lake or lakes? Admitting the erosion phase at the Kimmerian–Pontian boundary and noting, following Eberzin (1940), the direct inheritance of the fauna peculiar of the Azov Beds from the Pontian one, Semenenko (1987, p. 94) arrives at the interesting conclusion: "... the fauna of the Azov Beds corresponds in time to the stratigraphic hiatus between the Pontian and Kimmerian, moreover, to **its upper part only** (emphasis is mine, **I.Ch.**), but not to the entire hiatus. In the complete sections, the lower part of this hiatus could probably be filled with the *Moquicardium* Beds." Leaving aside the age problem of the latter (its position in the Caucasian sections still remains unclear), let us consider the fauna corresponding to the hiatus range and the problem of dividing the hiatus into the lower and upper parts. When the Semenenko's concept of the short-term existence period of almost freshwater lakes within the area of the modern Black Sea is followed, then the brief history of their malacofauna should include two stages. In case that the "late" stage corresponds to the Azov time (after Semenenko), the "early" one, naturally, should be that of the Pontian. In my opinion, such interpretation is implausible because the Azov Beds represent a distinct transgressive phase in the basin development, whereas sediments of the above-mentioned freshwater lakes could correspond only to the regressive phase. It is reasonable to assume that forms like *Paradacna deformis* (Ebers.) occurring at the very base of the Azov Beds in the Taman' section originated precisely in these hypothetical lakes at the early stages of the Epi-Pontian.

It is worth to mention observations by Semenenko and Lyul'eva (1982, pp. 65, 66) concerning the relatively deep-water facies of the Pontian and Azov beds in the Zheleznyi Rog section: "The uppermost layers of this (Pontian, **I.Ch.**) reversibly magnetized sequence are marked ... by the first occurrence of the early Kimmerian molluscan forms, for instance, of the early Kimmerian *Paradacna deformis* replacing the Pontian *Paradacna abichi*." Later, discussing the same section, Semenenko (1987, p. 146) writes: "There, the boundary between the Kimmerian (Azov Beds) and Pontian is within the **uppermost part of the *Valensiennius* Clay** (emphasis is mine, **I.Ch.**), where Pontian *Paradacna abichi* R. Hoern is replaced by early Kimmerian *Paradacna deformis* Ebers., and changes in the upper Pontian fauna are visible only at the species level."

If this Semenenko's observation is correct, then his conclusion that fauna from the Azov Beds corresponds in time to the upper part of the considered section cannot be viewed as valid.

Let us compare the above-described transition from the Pontian to Azov beds with the description of the same interval given by Andrusov as early as in 1903 (Andrusov, 1961, p. 616). The *Valensiennius* Clay member (according to Andrusov's nomenclature, Bed 14) is overlain by Bed 15, which includes Subunit 15a "... of highly ferruginous, clayey, fairly hard, dark brown marl enclosing casts with partly preserved shells." Higher, Andrusov described Subunit 15b of the same bed, which is composed of bluish gray clay, and then a bed of "bluish gray substance" overlain by brown iron ores.

According to Bogdanovich and Buryak (1986, p. 148), "the Pontian–Kimmerian boundary in the section of the Zheleznyi Rog Cape is marked by brownish gray marl (0.35 m) and gray calcareous clays (0.5 m) with *Paradacna deformis* Ebers. and *Pterodacna edentula* (Desh.) which are overlain by a bed (2 m) of brown iron ore with the diverse Kamyshburun fauna." These authors also emphasize the occurrence of the brown ferruginous marl bed (to 0.2 m thick) with *Dreissena rostriformis* (Desh.) and *Pterodacna praeedentula* Ebers. and the 20-m-thick member of gray clay with *Paradacna deformis* in the area between the Panagiya and Tuzla capes.

I visited the Zheleznyi Rog section many times and made several additions to description presented above. For instance, the dark brown marl should be classed, in my opinion, with the calcareous clay, because carbonate is distributed very unevenly. Its coloration varies from red to dark brown. The characteristic feature of the rock consists in irregular spotty gypsum accumulations; shell fragments bear distinct dissolution signs visible on breaks and ribs. Clay shows marks of plant root systems that suffered gleying. By combination of features, this layer can be defined as the buried soil. The layer from 0.3 to 1.2 m thick is traced over a distance of 40 to 50 m.

The buried soil is developed after gray calcareous Bosphorian clays enclosing deformed shells of *Valensiennius* and *P. abichi*. Shells of *P. deformis* are buried in gray clays only above the buried soil distinctly separating the Bosphorian and Azov beds.

V.N. Buryak and V.A. Prisyazhnyuk, the well-known researchers of the Neogene in the Eastern Paratethys, who kindly agreed to visit this section and investigate the Pontian–Kimmerian contact, completely shared my interpretation of the "brown marl" member as a buried soil developed after Pontian deposits. No joint occurrence of *P. abichi* and *P. deformis* below and above the soil bed was registered during the excursion.

In his recent description of the same section (*Neogene Stratigraphy...*, 1996, p. 17), S.V. Popov makes a distinct error considering, similarly to Semenenko (1987), the bed 15a ("brownish gray ferruginous solid marl") as representing the basal Kimmerian layer, because transgression of the Azov time could not start with formation of buried soil.[6]

Westward, in the syncline core between the Zheleznyi Rog and Panagiya capes, the boundary between Pontian and Azov Beds is also marked by the brown clay bed (to 0.25 m thick) separating beds of similar gray clay, one yielding *P. abichi* and another *P. deformis*. In the considered case, this basal member of the Azov Beds most likely represents the reworked Pontian red soil or weathering crust. It is interesting that the considered boundary lacks in this area, like in the Zheleznyi Rog and many other sections, the classical features of transgression (pebbly deposits, sands, and others). It is completely identical to transgressive sections of the basal Zanclean Stage and marks an "instant" transgression characterizing the initial Pliocene in both the Mediterranean and Euxinian basins.

Going back to my hypothesis that a distinct hiatus must exist in the uppermost part of the Pontian Stage and, correspondingly, that a gap about 100–150 k.y. long is in the Euxinian regional scale, I should admit that the deep-sea drilling data from the Black Sea do not help in answering the question formulated above. Stratigraphy of the drilled section is doubtful because it does not lean on distribution of calcareous nannoplankton.

A strange situation is brought about: the terrestrial Neogene sections in the marginal areas of the Euxinian basin enclose the nannoplankton assemblages, the zonal species included, whereas nannofossils are either missing or very rare in the sections drilled in the deep part of the sea that is unfavorable for sufficiently unambiguous age estimates of the drilled rocks. Discussing the results of the diatom-based subdivision of the deep-sea sections in the Black Sea, Jouse and Mukhina (1980, p. 57) call into question the data by Lyul'eva on the nannofossil assemblages from the Maeotian and Kimmerian layers of the Kerch' Peninsula stating that "the coexistence of true marine nannoplankton forms and brackish- to freshwater diatoms is in contradiction with the nature of both groups."

[6] During the earthquake of 1974, the large block including the considered section was displaced to the slope base and turned into the chaotic rock mass.

It should be noted that the insignificant abundance of nannofossils in sedimentary sections of the Paratethys, as compared with sediments of sea basins with the normal salinity, dictate, in opinion of Lyul'eva (1989), the need in the thorough study of preparations. Precisely the nontraditional method of nannofossil extraction allowed Lyul'eva to obtain micropaleontological materials very important for subdivision of the Neogene sections. Simultaneously, description of beds with nannofossils performed by Semenenko and Lyul'eva (1982) lacks evidence for the occurrence of brackish-water mollusks in them. For instance, my impression after reading the description of the Borehole 15 section is that malacofauna and nannofossils occur in different layers, and the presence of one group appears excluding the occurrence of another one. It is important that the authors provide no evidence for coexistence of nannofossils and malacofauna in any of the terrestrial sections, to say nothing of the fact that their descriptions lack the precise positioning of paleontological finds.

My own experience allows me to think that the brackish-water fauna and oceanic nannoplankton occur in different layers, thus reflecting the history of complex interrelations between two basins—the Tethys and Paratethys. It seems that the problem can be solved only there, where distribution of paleontological finds is exactly established in sections supplemented with the thorough and careful description. In any case, it can be stated that the poor knowledge of the Neogene deep-facies sections on land is a primary cause of unsuccessful subdivision of sections drilled in the deep sea.

Focusing attention on the hiatus that preceded the transgressive deposition of the Azov Beds in the Kimmerian, researchers of the Neogene sections in the Eastern Paratethys explained this phenomenon by tectonic factors. For instance, Eberzin (1940, 1968) related the event to the pre-Kimmerian orogenic phase, Kozhevnikov (1985) to the Caucasian orogenic phase, etc. Admitting the potential influence of tectonic factors, I should note, however, that the discussed phenomena of the Miocene–Pliocene boundary time in the Euxinian basin were connected with dramatic events in the neighboring Mediterranean Sea, namely with its desiccation and subsequent "instant" transgression marking the onset of the Pliocene epoch, as well as with the global Pliocene transgression. Considering the possible factors responsible for changes in the hydrological regime of the Black Sea basin, Muratov (1951, p. 19) believed that these events "... were probably related to the uplift and subsidence of the northern Black Sea region together with the Russian platform, or to other movements of the earth crust rather than to sea-level fluctuations." Nonetheless, being aware that his conclusion can be ambiguous, Muratov noted: "... this problem cannot be solved so far." It should be noted that Muratov formulated his idea long before the deep-sea drilling in the Black Sea this basin, when none of the European geologists assumed the past existence of

the Messinian evaporite basin and the "instant" leveling transgression of the Zanclean time. In addition, significance of transgression related to the Pliocene climatic optimum has been understood mostly owing to investigations in the Antarctic during the last two decades.

Recent years represented a period of intense studies on the Sarmatian, Maeotian, Pontian, and lower Kimmerian pelagic sequences in the Taman' Peninsula. There is no question that new stratotypes of the different rank and significance will be defined in this area, including the boundary stratotypes of the Neogene stages and substages missing in the Eastern Paratethys. Therefore, it is important to objectively revise, using all available advanced methods, the results of previous investigations, to analyze the objective and subjective errors, and to reinterpret geological events that occurred in the Euxinian and Tethyan basins at the Miocene–Pliocene boundary time.

In my opinion, the Miocene–Pliocene boundary in the Euxinian basin corresponds to the base of the Azov Beds of the Kimmerian Stage. The Azov Beds proper are correlative with the period of the first "instant" Zanclean transgression that leveled the water surface in the World Ocean and Mediterranean Sea and marked the Miocene–Pliocene boundary over the globe.

The second Zanclean transgression in the Euxinian region was related to the sea-level rise during the Pliocene climatic optimum and flooded vast lowlands in the northern Black Sea region leaving behind the Kimmerian Kamyshburun Beds.

The late Pontian hiatus in terrestrial sections is probably a marker of the water discharge from the Bosphorian basin into the Mediterranean Sea, where the brackish-water lago-mare basins appeared in deepest depressions. Sediments accumulated in these depressions partly overlie Messinian evaporites and are, in turn, overlain by Zanclean sediments exemplifying sedimentation under conditions of normal salinity. The existence period of the late Messinian lago-mare basin in the Mediterranean region corresponds, in the Euxinian region, to the time of lacustrine sedimentation in the hypothetical Epi-Pontian basin, deposits of which are presumably preserved in the deep part of the modern Black Sea.

ACKNOWLEDGMENTS

I express my sincere gratitude to E.E. Milanovskii and V.T. Frolov for their helpful criticism during the manuscript preparation.

Reviewer M.A. Akhmet'ev

REFERENCES

Anderson, I., Antarctica Was Once Warm, Fossils Suggest, *New Sci.*, 1980, vol. 122, no. 1667, p. 30.

Andrusov, N.I., Geological Investigations in the Taman Peninsula, in *Izbrannye trudy* (Selected Works), Moscow: Akad. Nauk SSSR, 1961, vol. 1, pp. 593–660.

Berggren, W.A., Kent, D.V., Swisher, C.C., and Aubry, M.-P., A Revised Cenozoic Geochronology and Chronostratigraphy, *Spec. Publ. SEPM*, 1995, no. 54, pp. 129–212.

Bogdanovich, A.K. and Buryak, V.N., The Taman Peninsula, in *Stratigrafiya SSSR. Neogenovaya sistema* (Stratigraphy of the USSR. The Neogene System.), Moscow: Nedra, 1986, vol. 1, pp. 142–150.

Chumakov, I.S., The Lower Pliocene Deposits of the Mediterranean Sea Is a Facies of Instant Transgression ("Flood"), *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1974, vol. 49, no. 2, p. 114.

Chumakov, I.S., Late Cenozoic Radiometric Scale for the Paratethys, *Priroda*, 1993, no. 12, pp. 68–75.

Chumakov, I.S., Byzova, S.L., and Ganzei, S.S., *Geokhronologiya i korrelyatsiya pozdnego kainozoya Paratetisa* (Late Cenozoic Geochronology and Correlation of the Paratethys), Moscow: Nauka, 1992.

Eberzin, A.G., The Middle and Upper Pliocene of the Black Sea Area, in *Stratigrafiya SSSR, tom 12: Neogen* (Stratigraphy of the USSR, vol. 12: The Neogene), Moscow: Akad. Nauk SSSR, 1940, pp. 477–566.

Eberzin, A.G., Abstracts of Papers, *II nauchno-tekhnicheskaya konferentsiya po izucheniyu poleznykh iskopaemykh osadochnogo kompleksa yuga Ukrainy* (II Scientific–Technical Conf. on Mineral Deposits of Southern Ukraine Sedimentary Complex), Kiev: Kiev Gos. Univ., 1968, pp. 38–41.

Gurarii, G.Z., Kudasheva, I.A., Trubikhin, V.M., Fein, A.G., and Shipunov, S.V., Age of the Natskhor and Shirak Formations of Eastern and Central Georgia and the Problem of the Miocene–Pliocene Boundary: Paleomagnetism and Stratigraphy, *Stratigr. Geol. Korrelyatsiya*, 1995, vol. 3, no. 2, pp. 62–72.

Jouse, A.P. and Mukhina, V.V., Diatom-Based Upper Cenozoic Stratigraphy, in *Geologicheskaya istoriya Chernogo morya po rezul'tatam glubokovodnogo bureniya* (Geological History of the Black Sea according to the Deep-Sea Drilling Data), Moscow: Nauka, 1980, pp. 52–65.

Kozhevnikov, A.V., *Antropogen gor i predgorii. Geneticheskii analiz* (The Mountain and Piedmont Anthropogene), Moscow: Nedra, 1985.

Lyul'eva, S.A., *Ceratoliths* (Nannoplankton) of the Miocene and Pliocene Deposits of the Southwestern USSR, *Dokl. Akad. Nauk USSR, Ser. B: Geol., Khim. Biol. Nauki*, 1989, no. 11, pp. 14–18.

Lyul'eva, S.A., Nannoplankton of the Dacian Deposits of the Southwestern Ukraine, *Dokl. Akad. Nauk USSR*, 1991, no. 1, pp. 73–77.

Muratov, M.V., History of the Black Sea Basin in Relation to Adjacent Areas, *Byull. Mosk. O–va Ispyt. Prir., Otd. Geol.*, 1951, vol. 24, no. 1, pp. 7–34.

Neogene Stratigraphy and Palaeontology of the Taman and Kerch Peninsulas. Excursion Guidebook. Field Symposium 4–14th June, 1996, Moscow. Paleontol. Inst. Ross. Akad. Nauk, 1996.

Pevzner, M.A., Abstracts of Papers, *S'ezd "Glavnoe geomagnitnoe pole i problemy paleomagnetizma"* (Congress: "Main Geomagnetic Field and Paleomagnetic Problems"), Moscow, 1976, p. 73.

Pevzner, M.A., Middle Miocene–Pliocene Stratigraphy of Southern Europe according to Paleomagnetic Data, *Doctorate Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst. Acad. Sci. USSR, 1986.

Semenenko, V.N., *Stratigraficheskaya korrelyatsiya verkhnego miotsena i pliotsena Vostochnogo Paratetisa i Tetisa* (Stratigraphic Correlation of Upper Miocene and Pliocene Deposits of the Eastern Paratethys and Tethys), Kiev: Naukova Dumka, 1987.

Semenenko, V.N., and Lyul'eva, S.A., Direct Mio-Pliocene Correlations between the Eastern Paratethys and Tethys, in *Stratigrafiya kainozoya Severnogo Prichernomor'ya i Kryma* (Cenozoic Stratigraphy of the Northern Black Sea Area and the Crimea), Dnepropetrovsk: Dnepropetr. Gos. Univ., 1978, no. 2, pp. 95–105.

Semenenko, V.N. and Lyul'eva, S.A., Problems of Direct Correlation of Upper Miocene and Pliocene Deposits of the Eastern Paratethys and Tethys, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1982, no. 9, pp. 61–71.

Semenenko, V.N. and Pevzner, M.A., Upper Miocene and Pliocene Correlations of the Pontian–Caspian Region by Biostratigraphic and Paleomagnetic Records, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1979, no. 1, pp. 5–15.

Semenenko, V.N. and Teslenko, Yu.V., Geological Events of the Eastern Paratethys at the Miocene–Pliocene Boundary, *Geol. Zh.*, 1994, no. 1, pp. 58–68.

Tretyak, A.N., *Stratigraficheskii aspekt paleomagnitnogo izucheniya meotisa Azerbaidzhana* (Stratigraphic Aspect of the Maeotian Paleomagnetic Studies in Azerbaijan), Available from VINITI, 1990, no. 5103-B90.

Zubakov, V.A., *Global'nye klimaticheskie sobytiya neogena* (Global Climatic Events of the Neogene), Leningrad: Gidrometeoizdat, 1990.

Zubakov, V.A. and Kochegura, V.V., Magnetochronological Scale of the Recent Time (5 Ma), in *Geomagnitnye issledovaniya* (Geomagnetic Investigations), Moscow: Nauka, 1976, pp. 37–44.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 405–418. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 93–107.
Original Russian Text Copyright © 2000 by Kuz'mina, Taldenkova.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

Stratigraphy and Paleogeography of Marine Holocene (the Primor'e Shelf)

N. N. Kuz'mina and E. E. Taldenkova

Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

Received July 7, 1998; in final form, December 28, 1998

Abstract—Representative materials from sea drilling sites with complete geological records and detailed geological–geomorphological analysis of sediments in the Primor'e coast and shelf (lithological and paleontological methods combined with radiological dating) enabled stratigraphic subdivision and correlation of these sediments and reconstruction of Holocene paleogeographic events. Most significant environmental changes occurred in the initial Holocene time (10.3–10.0 ka ago) and at the beginning of the Boreal period (about 9 ka ago). The corresponding stratigraphic levels are marked by significant changes in lithology and compositions of palynological and diatom assemblages in response to climatic and sea-level fluctuations. Three thermal maximums: Boreal, Atlantic (optimum) and Subboreal, are distinguished in the Holocene.

Key words: *stratigraphy, correlation, shelf, Holocene, paleogeography, coast, Sea of Japan.*

INTRODUCTION

The paper presents the results of the long-term complex study of cores recovered from sea borehole sites and on sediments of coastal terraces in the Primor'e region. The obtained materials were used as a basis for the detailed stratigraphic subdivision of Holocene marine sediments in the Primor'e shelf and coast and for elucidation of paleogeographic events of that time.

Two key areas: the Vostok Inlet and Kievka Cove, were studied in detail within coastal regions of the southern and central Primor'e. The Vostok Inlet is a part of the Peter the Great Bay, the largest one in the Sea of Japan (Fig. 1). This closed-type inlet formed as a result of sea ingression into river valleys. The inlet bottom includes flooded depressions of the Litovka and Volchanka river valleys, whose stream channels are traceable to the depth of 70 m. Accumulative relief forms are the 4-m-high marine terrace in the corner part of the inlet, where a thick interbed of marine transgressive sediments is dated back to 5080 ± 300 years (MSU-916), and the alluvial–lagoonal terrace in the eastern coast of the inlet, where a thick horizon of arboreal–herbaceous peat is as old as 24300–34070 years (MSU-931, 932, 933, 1221, 1222, 1224) or 33800–45700 (GIN-6600, 6601, 6602, 6607) years.

The Kievka Cove is located northeast of the Peter the Great Bay (Fig. 1) extending from the open coastal area to the Sea of Japan shelf. It is less studied in geological aspect than southerly areas of the Primor'e region.

In terms of geomorphology, the Kievka Cove represents a bay open southward and formed as a result of sea ingression into a wide valley of the Kievka River. Most interesting among coastal–marine accumulative forms are two marine terraces. The lower terrace 3–4 m high that is observed in the Kievka, Melkovodnaya, and other neighboring bays is composed of sandy–gravelly sediments displaying rhythmical bedding and enclosing molluscan shells. The upper, younger marine terrace to 5 m high is located in the Kievka Cove coast between the old and new stream channels. Its surface is decorated with 18 beach bars separated by depressions .

MATERIALS AND METHODS

Basic materials for the complex stratigraphic research were obtained from deep reference boreholes drilled in the shelf (water depth of 16–70 m) using the floating drilling rig of Marine Geological–Research Expedition, PGTO "Primorgeologiya" (Joint-Stock Company "Dal'morgeologiya). The core length was 18–55 m. Core description and sampling were performed by Kuz'mina directly in the course of drilling. The material obtained by gravity corers was also used. The maximum thickness of Holocene sediments (about 31 m) was registered in Hole 132 drilled in the axial part of the Kievka depression, where the water depth is 16 m (Fig. 2). Seaward, their thickness decreases to 14 m in Hole 133 (water depth 34.5 m; Fig. 3) and to 3.0–7.5 m in the peripheral part of the depression (Hole 119, water depth of 35 m). In their lithological characteristics, sediments vary from coarse gravel to silt and pelite. In the coastal shelf zone, sediments are fine-grained and become coarser seaward.

Sediments were studied using several groups of methods: lithological (granulometric, mineralogical, and other procedures), paleontological (spore–pollen,

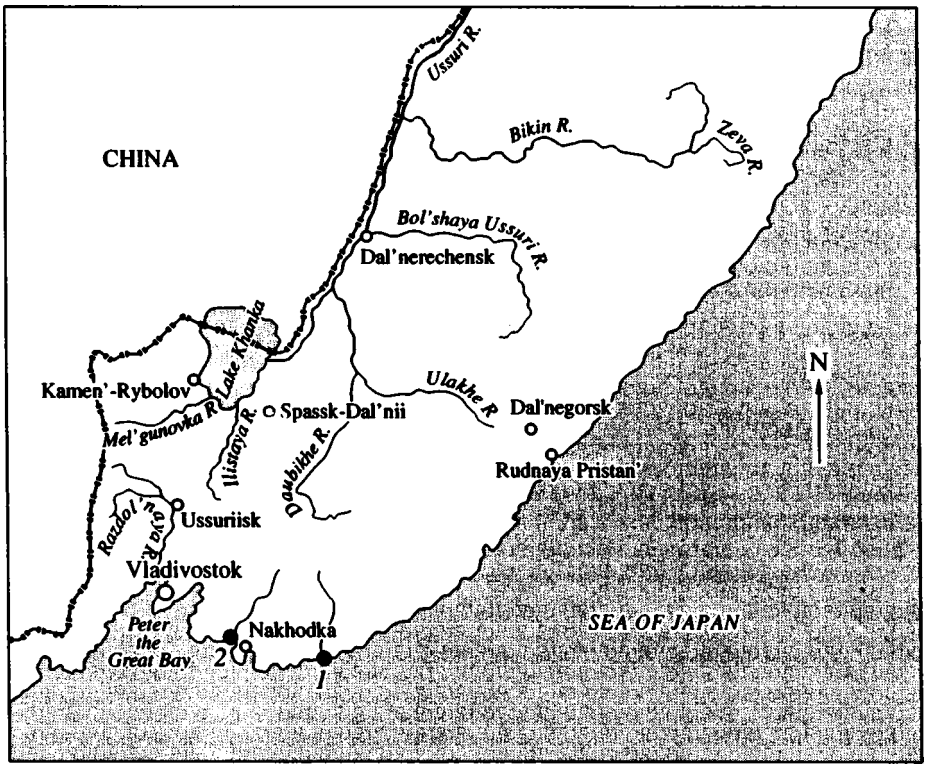


Fig. 1. Geographic scheme of the study area: (*1*) Kievka Cove; (2) Vostok Inlet.

diatom, malacological, and micropaleontological analyses), and radiological (^{14}C-dating). Simultaneously, the geological–geomorphological study of terraces was performed.

STRATIGRAPHY AND CORRELATION OF SHELF AND COASTAL SEDIMENTS. PALEOGEOGRAPHIC RECONSTRUCTION

In the continental shelf of the Primor'e region, the recovered heterogeneous sedimentary sequence includes the Middle–Upper Pleistocene and Holocene strata. In the stratigraphic scheme, the Holocene sediments are united into the Kievka Horizon named after the eponymous regional type section of Holocene marine sediments in the Primor'e. We propose to consider the study site as a stratotype area for the Holocene marine sediments for the entire Primor'e shelf of the Sea of Japan reasoning from the following facts.

(1) The area is relatively stable in tectonic aspect, as it was shown by several publications (Khudyakov *et al.*, 1972; Korotkii *et al.*, 1976; Kulakov and Pushkar', 1976; Kulakov, 1980). Accordingly, it can be the reference site for solving the problem of sea-level fluctuations during the Holocene (and also during the Pleistocene) in both the Far East and entire Northwestern Pacific.

(2) Sedimentation in the area was continuous beginning from the second Late Pleistocene cooling (Sartanian in the Siberian scale) to the Recent time.

(3) The section encloses layers with abundant shells and organogenic material, i.e., it has adequate paleontological substantiation, being dated in addition by the radiocarbon method.

The basal Holocene sediments overlie conformably, without a stratigraphic gap the deposits corresponding to the second Pleistocene (Sartanian) cooling and recovered from the depth interval of 13.8–21.4 m in Hole 133 (Fig. 3). Two horizons are distinguished in Holocene interval. The first one of silty deposits is 6 m thick and accumulated in the cold freshwater basin of the closed lacustrine type. This sedimentation period was independent of sea-level fluctuations characteristic of the thermal minimum in the first half of the Sartanian time, the main cooling period of the Pleistocene. Sediments rest upon the Kargino deposits dated back to 21400 years ago. The second horizon to 2 m thick is represented by alternating coastal-marine sands and silts and corresponds to the beginning of the postglacial transgression. Its section shows alternation of "cold" and "relatively warm" spore–pollen spectra reflecting unstable climatic conditions in the second half of the postglacial period. The rhythmical sedimentation pattern is evident from changes in lithological properties and diatom assemblages.

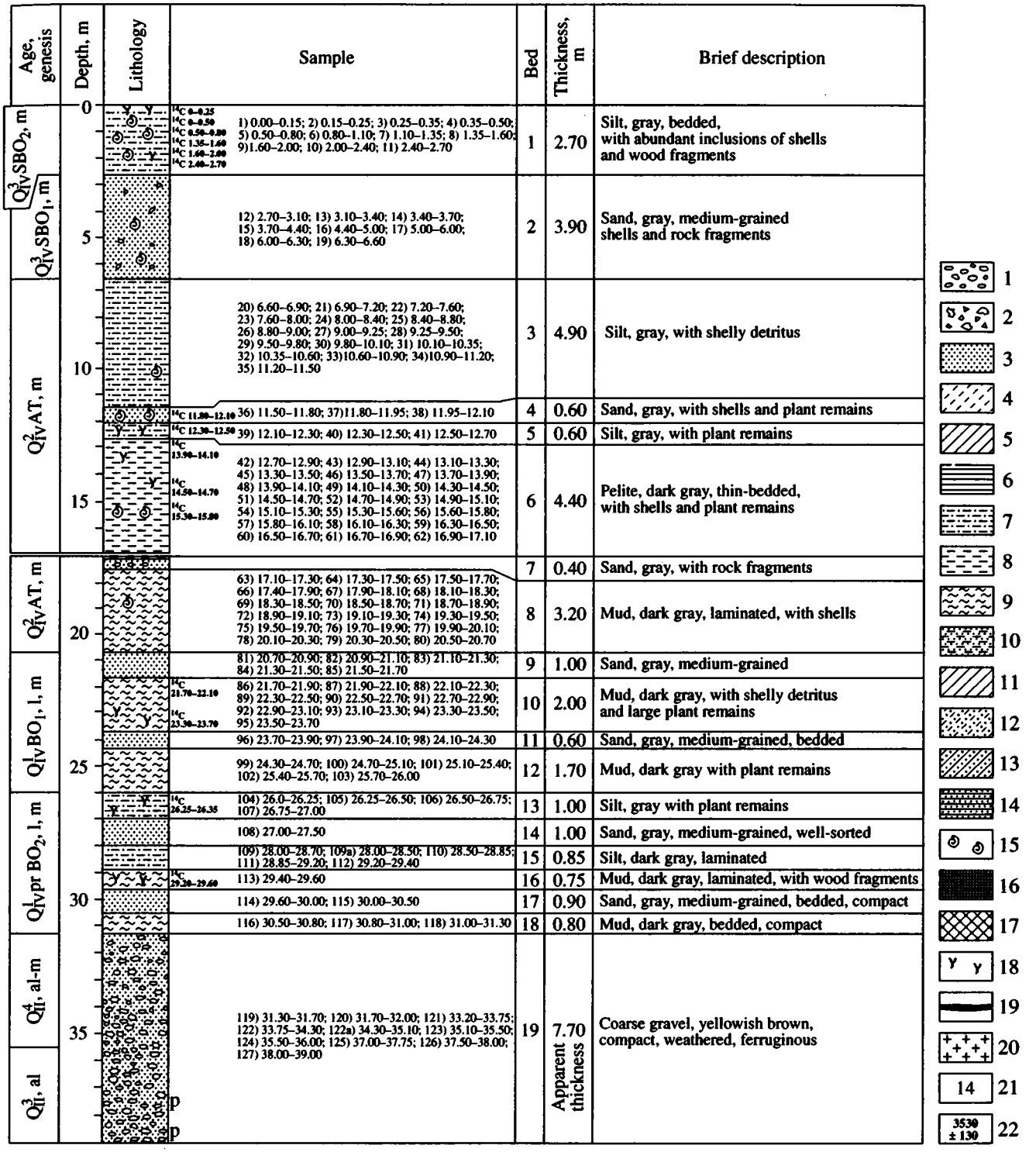


Fig. 2. Section recovered by Hole 132 drilled in the Kievka Inlet using the floating drilling rig, water depth of 16 m: (1) pebbly gravel; (2) rock debris, gruss; (3) sand; (4) sandy loam; (5) loam; (6) clay; (7) silt; (8) pelite; (9) mud; (10) muddy sand; (11) loam with gravel and pebble; (12) alternating sand and sandy loam; (13) alternating sand and loam; (14) alternating sand and clay; (15) molluscan shells and their fragments; (16) peat; (17) turf; (18) plant remains; (19) buried soil; (20) bedrock exposure; (21) number of stratigraphic layer; (22) radiocarbon dates.

Age, genesis	Depth, m	Lithology	Sample	Bed	Thickness, m	Brief description
$Q_{IV}^3SAT_1$, m	0		1) 0.00–0.20; 2) 0.20–0.40; 3) 0.40–0.60; 4) 0.60–0.80; 5) 0.80–1.00; 6) 1.00–1.20; 7) 1.20–1.40; 8) 1.40–1.60	1	1.60	Silt, gray, with shells
$Q_{IV}^2SBO_1$, m			^{14}C 1.60–1.80; ^{14}C 1.80–2.00; ^{14}C 2.00–2.20; ^{14}C 2.20–2.40 9) 1.60–1.80; 10) 1.80–2.00; 11) 2.00–2.20; 12) 2.20–2.40; 13) 2.40–2.60; 14) 2.60–2.80; 15) 2.80–3.00; 16) 3.00–3.20; 17) 3.20–3.40; 18) 3.40–3.60; 19) 3.60–3.80; 20) 3.80–4.00; 21) 4.00–4.20; 22) 4.20–4.45	2	2.85	Sand, gray, medium-grained with abundant shells and small-sized pebbles Sand, yellowish gray, coarse-grained with pebbles
$Q_{IV}^1BO_2$, m	5		23) 4.45–4.70; 24) 4.70–5.00; 25) 5.00–5.30; 26) 5.30–5.60; 27) 5.60–5.90; 28) 5.90–6.20; 29) 6.20–6.50; 30) 6.50–6.85; 31) 6.85–7.20	3	2.75	Coarse gravel, gray, with sand matrix
$Q_{IV}^1BO_1$, m			32) 7.20–7.45; 33) 7.45–7.70; 34) 7.70–8.00; 35) 8.00–8.30; 36) 8.30–8.50; 37) 8.50–8.80	4	1.60	Sand, gray, variable-grained with pebbles
			38) 8.80–9.00	5	0.20	Loam, brown–yellow, ferruginous
$Q_{IV}^1PBO_2$, m	10		39) 9.00–9.20; 40) 9.20–9.40	6	0.40	Silt, gray, bedded
			41) 9.40–10.00; 42) 10.00–10.20; 43) 10.20–10.40	7	1.00	Sand, dark gray, well-sorted
			44) 10.40–10.70; 45) 10.70–11.00	8	0.60	Coarse gravel, gray, with sand matrix
$Q_{IV}^1PBO_1$, m			46) 11.00–11.30; 47) 11.30–11.60; 48) 11.60–11.90; 49) 11.90–12.20; 50) 12.20–12.40; 51) 12.40–12.70; 52) 12.70–13.05; 53) 13.05–13.40; 54) 13.40–13.70	9	2.70	Sand gray, fine-grained with rare pebbles
Q_{III}^4, m			^{14}C 13.70–14.00 55) 13.70–14.00; 56) 14.00–14.30	10	0.60	Silt, gray, with plant remains
	15		57) 14.30–14.60; 58) 14.60–14.80	11	0.50	Sand, gray, medium-grained, thin-bedded
			59) 14.80–15.10	12	0.30	Silt, gray, laminated
			60) 15.10–15.45	13	0.35	Sand, gray, medium-grained
Q_{III}^4, l	20		^{14}C 17.30–17.50; ^{14}C 18.70–19.10; ^{14}C 20.00–20.80 61) 15.45–15.80; 62) 15.80–16.00; 63) 16.00–16.20; 64) 16.20–16.40; 65) 16.40–16.60; 66) 16.60–16.80; 67) 16.80–17.00; 68) 17.00–17.20; 69) 17.20–17.50; 70) 17.50–17.70; 71) 17.70–17.90; 72) 17.90–18.10; 73) 18.10–18.30; 74) 18.30–18.50; 75) 18.50–18.70; 76) 18.70–18.90; 77) 18.90–19.10; 78) 19.10–19.30; 79) 19.30–19.60; 80) 19.60–19.80; 81) 19.80–20.00; 82) 20.00–20.20; 83) 20.20–20.40; 84) 20.40–20.60; 85) 20.60–20.80; 86) 20.80–21.00; 87) 21.00–21.20; 88) 21.20–21.40	14	5.95	Silt, dark gray, displaying thin rhythmical lamination, with plant remains and wood fragments
			89) 21.40–22.10	15	0.70	Sand, gray, medium-grained
Q_{III}^3, m			^{14}C 23.00–23.30; ^{14}C 23.65–24.00 90) 22.10–22.45; 91) 22.45–22.80; 92) 22.80–23.00; 93) 23.00–23.50; 94) 23.30–23.65; 95) 23.65–24.00	16	1.90	Silt, gray, laminated, with plant remains
	25		^{14}C 24.00–25.00 96) 24.00–24.50; 97)24.50–25.00; 98)25.00–25.70	17	1.70	Sand, gray, variable-grained with pebbles and wood fragments
Q_{II}^4, m			99) 25.70–26.05; 100) 26.05–26.40; 101) 26.40–26.80; 102) 26.80–27.00; 103) 27.00–27.40; 104) 27.40–27.70; 105) 27.70–27.90; 106) 27.90–28.30; 107) 28.30–28.70; 108) 28.70–28.90; 109) 28.90–29.30; 110) 29.30–29.60; 111) 29.60–30.00; 112) 30.00–30.40; 113) 30.40–30.70; 114) 30.70–31.00; 115) 31.00–31.30; 116)31.30–31.60	18	5.90 Apparent thickness	Coarse gravel, gray–brown, with sandy–clayey matrix, compact, weathered, ferruginous
	30					

Fig. 3. Section recovered by Hole 133 drilled in the Kievka Inlet using the floating drilling rig, water depth of 34.5 m (symbols as in Fig. 2).

The base of the Holocene sediments was detected at the depth of 48–49 mbsf. This level corresponds to a distinct climatic warming at the Pleistocene–Holocene boundary that is registered by the palynological data in Hole 133 in the depth interval of 11.0–13.8 m. Hypsometrically, this boundary distinctly coincides with the base of Holocene sediments established in Hole 132 (Fig. 2) and dated as 9660 ± 160 years old (MSU-822). The available data on Holocene sediments in two large areas of the Primor'e region are used for their detailed subdivision and recognition of beds, which are correlated with horizons of the Blitt-Sernander's scheme

(Khotinskii, 1977) and termed as the pre-Boreal (PBO), Boreal (BO), Atlantic (AT), Subboreal (SBO), and Subatlantic (SAT) sediments (Kuz'mina *et al.*, 1987; Kuz'mina and Shumova, 1992; Kuz'mina and Postolenko, 1995; Kuz'mina, 1994, 1995; Kuz'mina and Taldenkova, 1995).

Pre-Boreal sediments (PBO) are subdivided into two (PBO_1 and PBO_2) layers. The **layer PBO_1** is represented by marine shallow-water well-sorted sands (Hole 133, depth interval of 11.0–13.8 m) with a low content of newly formed minerals (to 8%); the latter seems to be a consequence of an insignificant amount of active organic matter in sediments. Sands accumulated under oxidizing conditions and relatively active hydrodynamics. Their diatom assemblage is dominated by marine species, most diverse amid which are sublittoral and neritic, mainly arctic-boreal and cosmopolitan species (*Thalassiosira nordenskioldii, T. decipiens*). Among brackish-water species, most abundant are *Cocconeis scutellum* and *Diploneis smithi*. Freshwater diatoms are diverse and include riverine planktonic (*Tabellaria fenestrata, Aulacosira baicalensis*) and benthic species, rheophile included (*Cyclotella meneghiniana, Cymbella sinuata*, and others), which are characteristic of flowing waters. Freshwater diatoms were transported into the coastal zone by rivers.

As compared to the Sartanian time, the PBO_1 spore–pollen spectra are characterized by the much higher share of broad-leaved pollen (to 40%) mainly representing *Quercus* (to 33%) and *Ulmus* (to 80%). Coniferous pollen is that of *Pinus koraiensis* (to 24%), *Picea* sect. *eupicea* (to 16%), and *Abies* (to 5%). The content of spores including those of *Osmunda* cf. *cinnamonea* (to 25%), an indicator of the warm and humid climate, also increases. The cold-resistant elements are represented by pollen of *Larix* (to 18%), of *Betula* sect. *nanae* et *fruticose* (single grains), and *Alnaster* (to 6% and less). The palynological composition indicates significant changes in the vegetation cover and climatic warming at the Pleistocene–Holocene boundary.

The beginning of the Holocene coincided with expansion of coniferous–broad-leaved forests, whose preponderant constituents were *Picea, Pinus koraiensis, Quercus*, and *Ulmus*. Quantitative climatic parameters were obtained using the informational–statistic method (Shumova *et al.*, 1986). During the PBO_1 period, the average annual, summer (July), and winter (January) temperature values were respectively by 3–4, 2, and 4–5°C lower than at present, and precipitation was by 50 mm lower (Table).

The **PBO_2 layer** was recovered from the depth interval of 9–11 m in Hole 133. These coastal-marine, moderately sorted sands are coarser than the underlying sediments. With respect to mineral composition, their heavy fraction contains a significant amount of newly formed Fe and Mn hydroxides (to 38%) characterizing oxidizing conditions of sedimentation. Rock clasts are also abundant in this fraction. In Hole 132 (depth interval of 26.0–31.3 m; age 9660 ± 160 years, MSU-822), sediments of the PBO_2 layer correspond to intercalated sand and silt of the lagoonal and lagoonal–marine origin. The heavy fraction is dominated here by terrigenous minerals (hornblende) and rock clasts; ilmenite is missing. Newly formed minerals are diverse (Fe hydroxides, pyrite, carbonates, and others), although rare. The clayey substance is of terrigenous origin (data on thin section study) and shows no alteration signs. This is an evidence of severe climatic conditions during the rock formation.

The diatom assemblage mainly consists of freshwater and brackish-water species such as *Achnanthes minutissima, Navicula pupula*, and *Cymbella ventricosa*. Rheophile *Meridon circulare* et v. *constricta* are also present. Marine diatoms are represented by rare neritic (*Thalassiosira gravida*) and sublittoral (*Rhaphoneis surirella, Melosira sulcata, Opephora marina, Cocconeis scutellum*) species. In the group of brackish-water species (29%), preponderant are *Diploneis smithi* and its varieties. The difference between the PBO_2 diatom assemblages from different holes reflects peculiarities of sedimentation settings: sediments from Hole 132 accumulated in the freshened lagoon with the permanent, though limited water exchange with the sea, whereas those from Hole 133 located seaward were deposited in the bar that isolated the lagoon at the beginning of the Holocene, i.e., during the PBO_1 time.

As compared with sediments of the initial Holocene (PBO_1), the overlying unit shows an increased amount of *Betula* sect. *fruticose et nanae* (to 35%), *Alnaster* (to 38%), and *Larix* (to 30%) in the spore–pollen spectra. The pollen share of broad-leaved plants decreases to 9–30%, and *Ulmus* pollen represents 21% in this group. *Osmunda* disappears from the spore assemblage, where *Lycopodium* cf. *pungens* (to 14%) and *Selaginella sibirica* (to 11%) are newcomers.

The second half of the Preboreal period corresponds to a significant cooling, when the maritime plain was occupied by forest tundra with thin birch–larch forests and dwarfed birch communities. The areas of most favorable conditions hosted birch–elm forests, as it was noted by Neistadt (1957) for the early Holocene. According to our data, the average annual, summer (July), and winter (January) temperature values were by 6-8, 4–5, and 8–10°C, respectively, lower as compared with the same parameters at present, and precipitation was by 100–150 mm lower (Table).

The Boreal sediments recovered by Holes 132 and 133 are also subdivided into two units or BO_1 and BO_2 subhorizons. The most complete section of the BO_1 sediments is that recovered by Hole 133 (depth interval of 7.2–9.0 m) and consisting of gray moderately sorted coarse gravel. The heavy rock fraction is dominated by terrigenous components (rock clasts, hornblende, and others), and the newly formed minerals are represented by Fe and Mn oxides–hydroxides (to 32%). Similarly to underlying sands with pebbles (PBO_1), these sedi-

Variations of climatic characteristics and sea-level fluctuations in the Sea of Japan during the Holocene

Age	Horizon	Subhorizon		Ka	Index	Bed	Radiocarbon date, ka	Climatic characteristic	Sediment type	Sea-level fluctuations	
Holocene	Kievka	upper	Subatlantic	2.5	Q^3_{IV}	SAT_3	160 ± 110 720 ± 150	t = 3–4°C precipitation = 800–850 mm	Marine, relatively deep-sea, coastal-marine	Postglacial transgression	Modern Sea level rise by 2.5–3.0 m
						SAT_2	1400 ± 200 1420 ± 180				
						SAT_1					Sea level fall
		middle	Subboreal		Q^2_{IV}	SBO_2	3530 ± 130	t by 1–2°C higher than at present			Sea level rise by 1.5–2.0 m
						SBO_1	4740 ± 125	t by 1–2°C lower than at present, precipitation similar to the modern one			Sea level fall
			Atlantic	5.0		AT_3	5080 ± 300 5790 ± 110 6260 ± 110	t by 2°C and precipitation by 50–100 mm higher than at present (optimum)			Sea level rise by 2–3 m (maximum phase)
						AT_2	6300 ± 570 6790 ± 90				
						AT_1	7370 ± 140 7360 ± 250				
		lower	Boreal	8.0		BO_2		t by 2°C and precipitation by 25 mm lower than at present	Coastal-marine, lagoonal		
						BO_1		t by 1–2°C lower than at present and by 8–10°C higher than that of PBO_2; precipitation similar to the modern one			Gradual sea level rise with two pauses
			Preboreal	9.3		PBO_2	9660 ± 160	t by 6–8°C and precipitation by 100–150 mm lower than at present			
						PBO_1		t by 3–4°C and precipitation by 50 mm lower than at present			
Pleistocene	Second cold	upper		10.3	Q^4_{III}	8			Lacustrine–marine, coastal-marine		–49 m
		middle				7					
						6					
						5					
						4				Regression	
		lower				3			Palustrine		
						2	15300 ± 1000	t by 10–11°C and precipitation by 150–200 mm lower than at present	Lacustrine		
				22–25		1	21400–24300				–120 m

ments accumulated in oxidizing environments under influence of relatively active hydrodynamics. In Hole 132, the BO_1 sediments (interval of 20.7–26.0 m) are represented by alternating gray sand and dark gray mud of the lagoonal genesis; these rocks yield shelly detritus and plant remains. In the mineral composition, the rocks significantly differ from coeval sediments of Hole 133 showing preponderance of terrigenous components (hornblende and rock clasts) and virtual absence of authigenic minerals. The difference reflects peculiarities of sedimentation in the hole sites.

Preponderant amid diatoms are marine species: oceanic (*Coscinodiscus oculus-iridis, Thalassiothrix longissima*), cold-resistant neritic (*Thalassiosira nordenskioldii, T. gravida, Chaetoceros* sp), and sublittoral (*Paralia sulcata, Rhaphoneis surirella, Cocconeis vitrea, C. scutellum, Opephora marina*). Abundance of marine diatoms in sediments from Hole 132 is up to 8–14%. Hole 133 yielded euryhaline brackish-water marine diatoms *Cocconeis scutellum* and *Diploneis smithii* in association with freshwater *Achnanthes atacame, Cymbella ventricosa*, and *Synedra* sp. Most significant changes in the diatom flora are registered at the depth of 9.0 m in Hole 133, where the species diversity of freshwater diatoms is 1.5 times lower and abundance of marine species increases. This level is accepted as representing the boundary between the PBO and BO layers. In general, the low abundance of marine diatoms in Hole 132 indicates their suppressed state. Conditions were favorable only for euryhaline species adapted to significant salinity variations. Freshwater halophilic species were subordinate and of low diversity (*Achnanthes hauckiana, Gomphonema parvulum, Navicula mutica*). Preponderant were indifferent species adaptable to the water salinity of 5‰ and less. Thus, the diatom assemblages in BO_1 sediments of Holes 132 and 133 are slightly different, dependent on facies variations. However, the diatoms in general characterize environments of a shallow basin freshened under influence of river influx and enclosing local stagnant settings.

The beginning of the Boreal period corresponds to significant changes in composition of palynological spectra indicative of a sudden substantial warming. As compared with underlying Preboreal layers, sediments at this level show five- to six-fold increase in the share of pollen of broad-leaved plants (to 48%) and their greater diversity. The assemblage is mainly represented by pollen of *Quercus mongolica, Q. dentata* (37–43%), *Ulmus* (6–14%), and others. Abundant is also pollen of *Betula* sect. *albae* (25–44%). The content of coniferous pollen slightly increases, whereas that of cold-resistant elements is reduced.

The forest–steppe landscape of the period under consideration was marked by development of broad-leaved, mainly oak forests with the birch admixture. Open areas were dominated by sedge–gramineous meadows and herbaceous–wormwood steppes. The average annual and summer (July) temperature values were by 1–2°C higher and those in winter (January) by 0.5–1°C lower as compared with the present parameters, whereas precipitation was approximately the same (Table).

The BO_2 sediments of Hole 133 in the depth interval of 4.5–7.2 m are represented by coarse gravel, relatively well-sorted. Their heavy fraction is characterized by a high content of authigenic minerals such as the Fe and Mn oxides–hydroxides (to 40%). The diatom assemblage includes mainly marine species: oceanic (*Coscinodiscus oculus-iridis, Thalassiothrix longissima*), neritic arctic-boreal and bipolar cold-resistant (*Thalassiosira gravida, T. hyalina*), and different sublittoral forms (*Paralia sulcata, Cocconeis vitrea*, and other species). Freshwater and brackish-water species are represented by *Aulacosira italica, Cocconeis pediculus, Cymbella ventricosa*, and others.

The second half of the Boreal period coincided with a slight cooling event that is reflected in palynological spectra. The share of cold-resistant elements (*Betula* sect. *fruticosae* et *nanae* and *Alnaster*) increases in the pollen group of generally thermophilic vegetation to 14 and 4%, respectively. Local thin larch forests coexisted with preponderant birch–oak forests, thus reflecting a relative cooling, which is also registered in sediments of Hole 132. The average annual, summer (July), and winter (January) temperature values were respectively by 2, 1, and 2–3°C lower as compared with the modern parameters, and precipitation was by 25 mm lower (Table).

Thus, sediments of the Preboreal and Boreal stages are recovered in the shelf at depths of 48–36 mbsf. They are of the ingressive type, corresponding to the onset of the Sea of Japan ingression into the Kievka River valley. This time period resulted in formation of the marine accumulative structure, the bay barrier, which accumulated mainly the material from abraded river sides and isolated the cove from the sea. The ingression rate was significant, amounting to 8 mm/year. The sea-level rise was probably compensated by sedimentation. According to our calculation, the sedimentation rate in depression was 7.5 mm/year during the Preboreal time and decreased to 3.0 mm/year in the Boreal period. The Preboreal–Boreal boundary marks significant changes in topography, sedimentation, and climate. The quick and substantial climate warming favored an intense expansion of broad-leaved forests in the study area. The warming event increased the average annual temperature by 8–10°C as compared with that of the Preboreal cooling period and by 1–2°C in comparison with modern parameter (Table). During this warming episode, the forest tundra landscape was replaced by the forest steppe, where arboreal communities were of the birch–broad-leaved (mainly oak) type.

Of significant importance for paleogeographic interpretation are archeological data. Distribution patterns of ancient human sites are determined by specific

features of economic activity of ancient man that depended on the level of social-economical evolution and environmental conditions. The study of archeological memorials in the Melkovodnaya, Kievka, Avangard (Vostok Inlet) areas showed that the Early Holocene represented a time, when ancient humans only began their seaward movement from internal areas of the continent to settle on structural–erosional terraces 20–40 m high near river mouths. The main economical activity at that time was hunting in internal land areas (Kuz'mina and Stepanov, 1984).

The sediments of the Atlantic age (AT) corresponding to the climatic optimum of the Holocene are recovered by Holes 132 (depth interval of 6.5–20.7 m) and 180; they are also exposed at the base of the lagoonal and marine terraces along the Kievka Cove and Vostok Inlet coasts. In the shelf, sediments of the Atlantic time are fine-grained, represented by mud, pelite, and silt with rare dark–gray sandy interbeds; the rocks bear molluscan shells and plant remains. On the coast, these are mud and sand beds with abundant molluscan shells.

Shelf sediments of the Atlantic period are characterized by the gradual increase in the average dimension of grains and roundness degree to 0.45 upward in the section. The heavy fraction includes diverse newly formed minerals, whose proportion amounts to 80%. In addition to pyrite, different modifications of siderite and also glauconite, which is missing in other intervals, are present. The occurrence of glauconite indicates the marine genesis of sediments in a setting presumably enriched in organic matter that originated in the upwelling zone. Consequently, sediments were deposited at a significant depth under conditions favorable for organic matter accumulation and precipitation of newly formed minerals. The C_{org} content is up 1.06–2.27%. The terrigenous influx was probably insignificant due to the increased depth of the basin, whereas climatic conditions were favorable for transport and accumulation of fairly abundant organic matter. The diatom assemblage shows a sharp increase in the share of marine and brackish water species to 50% in the lower part of the sequence and to 96% in its middle and upper parts. Preponderant diatoms are neritic *Thalassiosira nordenskioldii* and *Thalassionema nitzschioides* accompanied by subordinate oceanic forms *Coscinodiscus marginatus* and *C. curvatulus*. Sublittoral species *Rhaphoneis surirella, Cocconeis scutellum*, and others are also abundant. Freshwater diatoms are diverse, but not abundant, occurring as "single" and "rare" specimens. The taxonomic composition of diatom assemblages, proportions of various ecological groups, and lithological–mineralogical data allow an assumption that sediments accumulated in a relatively deep marine bay under warm climatic conditions.

Foraminifers from the Atlantic sediments are characterized by the following features: (a) their maximum abundance is 3368 specimens/g of dry sediment; (2) the maximum diversity is 24 species; and (3) calcareous benthic forms are preponderant in assemblages. Dominant forms are *Elphidium selveyense, Protoelphidium aster tuberculatum, Cribroelphidium granatum, Buccella frigida, B. hannai arctica*, and *B. inusitata*. The most thermophilic species is *Buliminella elegantissima*. All listed species occur everywhere in the western shelf of the Sea of Japan at depths above 120 m being most abundant at the depth of about 50 m. Sediments accumulated in the shelf under low positive bottom temperatures and salinity parameters close to normal. Present planktonic foraminifers are represented mostly by juvenile and dwarfed forms that implies the relatively deeper sedimentation settings influenced by currents.

The sediments under consideration enclose two molluscan assemblages (Taldenkova, 1994). The first of them is buried in muddy sediments at the depth of 16.3–16.8 m (Hole 132) and represented by large and massive well-preserved shells. The assemblage is dominated by subtropical species *Crassostrea gigas* accompanied by subordinate *Mya japonica, Macoma orientalis*, and *Pandora* cf. *wardiana*. The molluscan assemblage is thermophilic in general, mostly represented by subtropical and low boreal species. Shells were dated using the ^{14}C method and are 7360 ± 250 years old (MSU-802). The molluscan assemblage discovered in the overlying sandy layer (depth interval of 11.8–12.4 m) is referred to the same period of time. Shells are fragmented at this level. Dominant *Crenomytilus grayanus*, the low boreal species, is accompanied by *Protothaca staminea, Crassostrea gigas*, and several small gastropod forms. The assemblage lacks cold-resistant species. The shallow-water species are most abundant, although they associate with relatively deep-sea forms such as *Suavodrillia kennicottii* dwelling at depths of 50–60 m. The ^{14}C dating of shells from this assemblages yielded the age value of 7370 ± 140 years (MSU-830).

Palynological spectra in sediments of the Atlantic time show predominance of pollen of arboreal broad-leaved plants (36–77%), mainly of *Quercus mongolica* and *Q. dentofae* (32–72%). Other thermophilic constituents are also diverse and include *Ulmus* (three species), *Corylus, Tilia* (three species), *Carpinus betulus, C. cordata, Uglans manshurica, Rhellodendron*, Araliaceae, and *Syringa*. Abundant is also pollen of arbuscular birch, mainly of *Betula* sect. *albae* (to 52 %). Pollen of cold-resistant plants is virtually absent. Amid herbaceous pollen, preponderant is that of *Artemisia* (26–58%), whereas the share of Graminae pollen is reduced (8–29%). Similar spectra are also obtained for sediments occurring at the base of 3.5-m-high lagoonal terrace. The corresponding climate was slightly warmer and drier than the modern one.

The vegetation cover was dominated by broad-leaved and birch–broad-leaved forests with preponderant oak and different thermophilic forms: *Ulmus, Cory-*

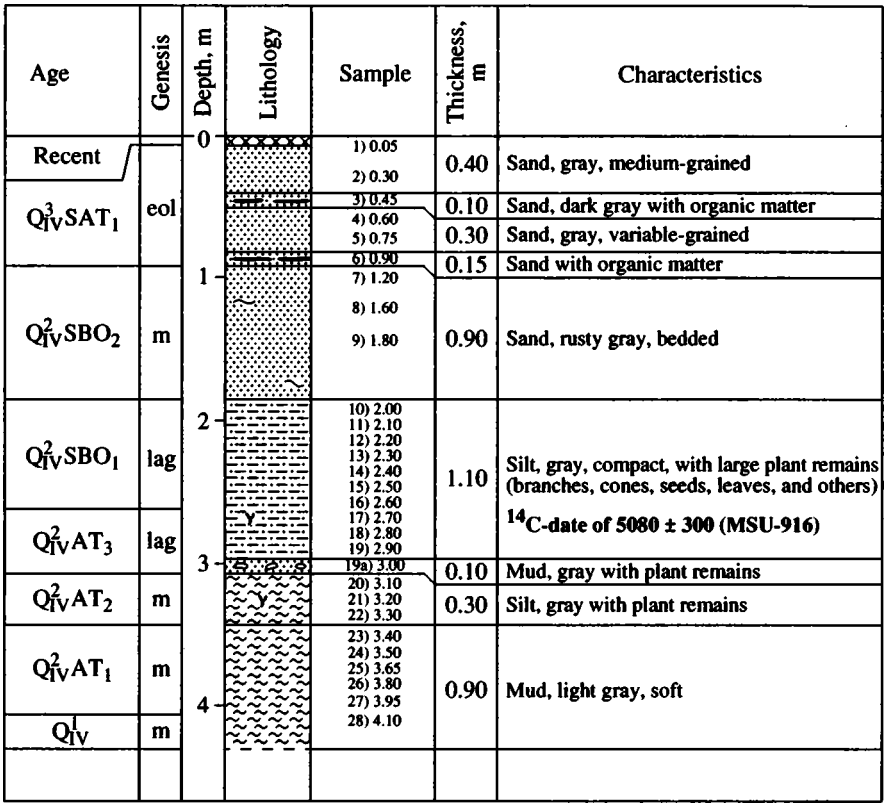


Fig. 4. Excavation 100 (3–4-m-high marine terrace in the vicinity of the Avangard Settlement, the Vostok Cove; symbols as in Fig. 2).

lus, Juglans, Carpinus, Tilia, Phellodendron, Fraxinus, Acer, Araliaceae, and others. Open landscapes were occupied by herbaceous–wormwood steppes. The climate was warmer as compared with the modern one. All annual temperature characteristics were by 2°C higher in comparison with the corresponding modern parameters, and precipitation was by 50–100 m higher than nowadays (Table).

The onset of the coastal-marine sedimentation cycle accompanied by formation of the 3–4-m-high marine terrace of the Melkovodnaya Bay coincided with the maximum phase of the postglacial transgression. The terrace socle is composed of fine-grained lagoonal mud enclosing fossil molluscan shells. The roof of the mud unit is located 2 m above sea level. Its formation is referred to the second half of the Atlantic period (6000–5000 years ago according to the ^{14}C dating). The section of 3.5- to 4.0-m-thick lagoonal terrace, whose base is also composed of sediments accumulated during the Atlantic period, was studied in the neighboring Kaplunova Bay. The roof of the terrace socle is also located 2 m above sea level. Marine sediments of the Atlantic age also compose the socle of the 1st 5-m-high terrace above the floodplain of the Kievka River; the terrace is located 3–4 km upstream, and its socle roof is situated 2.5 m above sea level.

Sediments of the Atlantic period are also recovered around the Vostok Inlet in the Excavation 100 (Beds 1–6, Fig. 4) on the coast and by Hole 180 (depth interval of 0–0.5 m) in the shelf. In the self, these sediments are represented by silt and sand with molluscan shells that yielded the ^{14}C age value of 6300 ± 570 years (MSU-1028). The poorly sorted silt contains a significant clay admixture (to 35%). The heavy silt fraction is mainly composed of terrigenous minerals indicative of a significant influx of clastic material and highly active hydrodynamics. The diatom assemblage includes marine species *Thalassiosira excentrica, Cyclotella striata, Coscinodiscus oculus-iridis, Actinocyclus divisus, Odontella aurita, Thalassionema nitzschioides*, and others, thus being dominated by planktonic neritic and pantalassic forms. Freshwater diatom species are virtually absent.

The molluscan assemblage from the sandy layer of Hole 180 is of a mixed taxonomic and biogeographic composition. It includes species characteristic of depth zone of 40–50 m and shallow-water forms probably transported by bottom currents. The former are preponderant and represented by boreal–arctic *Tridonta borealis borealis* and *Serripes groenlandicus*, whereas the group of shallow-water forms includes *Pododesmus macroshisma, Ostrea* sp., *Macoma* cf. *incongrua*, and others. Bottom currents are very peculiar of this part of the gulf. They are characterized by high and variable velocities and frequently change their direction. Thus, the lithological–paleontological data and composition of diatom assemblages imply sedimentation in the

marine setting during the sufficiently high sea-level stand.

In the palynological spectra of these sediments, arboreal pollen is largely (34–46%) represented by moderately thermophilic broad-leaved *Ulmus* (16–40%), *Quercus mongolica* (12–41%), and others. Also present is pollen of *Betula* (12–43%) and *Alnus* (to 13%). Common in herbaceous pollen are grains of *Varia* (12–60%) and *Artemisia* (20–48%). Landscapes of that time were dominated by birch–broad-leaved forests with *Pinus koraiensis*. Climate was warmer than the modern one and moderately humid. The sequence formation during the Atlantic period of the Holocene is substantiated by the obtained ^{14}C date of 6300 years.

The Holocene sediments compose also the 4-m-high marine accumulative terrace composed of two members (Excavation 100, Fig. 4). The terrace section includes the following units (from the base upward):

(1) Soft fine-grained mud 0.3 m thick (visible thickness); according to spores–pollen analysis, the bed accumulated under relative cooling at the boundary between the Boreal and Atlantic periods of the Holocene.

(2) Compact silt with large plant remains (branches, cones, seeds, leaves, and others); the rock sample taken 2 m above sea level is dated back to 5080 ± 300 years ago (MSU-916) using the ^{14}C method. The silt is poorly sorted and contains siderite (96% of the heavy fraction). At the level of 2.85 m, the rock is saturated with plant remains, abundant are also Fe sulfides (to 55%). The palynological spectra are dominated by pollen of broad-leaved plants (71–76%), mainly of *Quercus* (25–40%) and less abundant *Corylus, Ulmus, Tilia, Erexinus, Juglans, Carpinus cordata*, and Araliaceae. Also present are *Pinus koraiensis* (5–26%) and some other taxa. The taxonomic composition of the assemblage is compatible with the Atlantic optimum of the Holocene that is confirmed by ^{14}C dating. It characterizes climate of the corresponding time as warm and moderately humid, favorable for development of broad-leaved forests. Using a thorough palynological analysis, we divided the unit under consideration into three members corresponding to respective phases of the vegetation development during the Holocene climatic optimum: (1) the phase of distribution of broad-leaved, mainly oak forests under warm moderately humid climate of the initial Atlantic period (AT_1); (2) the phase of reduced taxonomic diversity of broad-leaved forests and appearance of birch thickets among plant formations under conditions of relative cooling at the mid-Atlantic time (AT_2); and (3) the phase of development of broad-leaved forests under most favorable and warm climatic conditions of the second half of the Atlantic period (AT_3); this phase corresponds to the Holocene optimum proper and to the relevant flourishing episode of diatom flora and molluscan fauna. In the 4-m-high terrace, the base of the Atlantic interval (^{14}C date of 5080 ± 300 years ago; MSU-916) is located 2 m above sea level and implies the higher stand of the Sea of Japan level during the Holocene optimum (the maximum stage of postglacial transgression) as compared with the modern one. The results of facies–genetic and stratigraphic subdivision of the marine terrace section in the Vostok Inlet substantially clarify data on the Holocene optimum and its paleogeographic consequences.

The Atlantic period represents an epoch of environments most favorable for the development of vegetation cover. Its characteristic diatom, foraminiferal, and molluscan assemblages are most thermophilic for the entire Holocene and suggest higher water temperatures in the Sea of Japan. According to Pletnev (1985), the surface water temperature in the Sea of Japan was by 1–3°C higher during the Holocene optimum, as compared with this parameter at present. The Atlantic period was a time of wide development of postglacial transgression and sea-level rise by 2–3 m relative to the modern one (Kuz'mina and Shumova, 1992). The shelf accumulated relatively deeper-water sediments. According to our data, the sedimentation rate was up to 5.3 mm/year at that time. Accumulation of sediments in the shelf was accompanied in the coastal zone by formation of 2.5- to 3.0-m-high marine terrace and by deposition of basal sediments in the 3.5-m-high lagoonal terrace.

In the Atlantic time of the middle Holocene, sites of ancient man were typical of the coast, although they usually occupied elevated areas of terrace-like surfaces, because the lower levels were inaccessible owing to the high sea-level stand. The ancient man contacts with the sea coast are evident from occurrences of marine pebbles and shells specially brought to the sites located at the high levels. There are also seasonal and temporary sites located at the low marine accumulative terraces, usually around inlets. These sites have an appearance of hunting camps.

The Subboreal sediments (SBO) are penetrated in three boreholes (depth interval 0.8–6.5 m in Hole 132, 1.6–4.5 m in Hole 133, and 0.5–7.6 m in Hole 119) and studied in outcrops of the 3.5-m-high lagoonal terrace, at the base of 2.5-m-high terrace of the Kievka River, and of the 4-m-high marine terrace of the Vostok Inlet. Based on lithology, diatom, micro- and macrofossil assemblages, and palynological spectra, these deposits are subdivided into SBO_1 and SBO_2 subhorizons. Sediments accumulated under conditions of relative cooling of the first half of the Subboreal period (SBO_1) are sands with molluscan shells in the shelf and mud beds in the lagoonal and marine terraces. Deposits of the warming episode spanning the second half of the Subboreal period (SBO_2) are represented by shell-bearing silts in the shelf and by sands in the alluvial and marine terraces.

The subhorizon **SBO_1** is composed of moderately sorted sands with pebbles (Hole 132, depth interval of 6.5–2.7 m). The heavy fraction of these sediments is dominated, contrary to those of the Atlantic period, by

terrigenous minerals. Abundant are hornblende (to 40%), rock clasts, minerals of the epidote group, and ilmenite (to 2%). Authigenic minerals are very rare. It can be assumed that the sea depth decreased, as compared with the Atlantic time, and the terrigenous transport was activated again. Taxonomic composition of the diatom assemblage with the reduced abundance and diversity of marine species also indicates a slight sea-level fall. Most common among diatoms are sublittoral species *Rhaphoneis surirella, Cocconeis scutellum,* and *Trachyneis aspera. Synedra ulna* var. *amphirchinchus, Meridion circulare,* and *Cocconeis placentula* are dominant in the freshwater group. Coeval marine diatoms from Hole 133 are represented by cold-resistant arctic-boreal, north boreal neritic (*Porosira glacialis, Thalassiosira nordenskioldii, T. hyalina, T. gravida*) and sublittoral (*Paralia sulcata, Arachnoidiscus ehrenbergii, Navicula transitans*) species. The foraminiferal assemblage is dominated by *Buliminella elegantissima, Buccella frigida,* and *Elphidium subclavatum.* The occurrence of *Buliminella elegantissima* indicates normal salinity in the relatively deep sea basin.

The sandy member of Hole 133 (depth interval of 2.1–2.9 m) encloses mollusks, which yielded the ^{14}C date of 4740 ± 125 years (MSU-825). Shells are poorly preserved, and many their fragments are undeterminable. These deposits of the coquina facies (Evseev, 1981) most likely accumulated in a fairly shallow setting (5–10 m). In its composition, the assemblage is cold-resistant, including dominant boreal–arctic species *Liocyma fluctuosa, Macoma calcarea, Serripes groenlandicus,* and widespread boreal *Protothaca staminea.* A combination of cold-resistant fossils and shallow-water appearance of sediments is peculiar of the cold Holocene epochs in contrast to warm periods, when the well-heated shoals hosted mostly subtropical and low-boreal mollusks, whereas boreal–arctic species dwelt, similarly to their modern counterparts, in deeper bottom areas. For instance, the molluscan assemblage sampled from the sea bottom at depth of 35 m is dominated by boreal–arctic species *Tridonta borealis borealis* and *Serripes groenlandicus.*

According to palynological data, the onset of the Subboreal period favored development of dark coniferous formations consisting of *Picea* sect. *omorica,* and *P.* sect. *eupicea* (to 27%), *Pinus koraiensis* (16 %), and *Abies* (14 %); these formations and thickets of *Betula* sect. *nanae et fruticosae* (to 7%) and *Alnaster* (to 4%) coexisted with preponderant broad-leaved forests. The palynological spectra imply that the cooling event occurred 5000–4500 years ago. Similar spectra corresponding to cooling in the first half of the Subboreal period are detected in sections of the 3.5-m-high lagoonal terrace of the Kaplunova Bay and of the 4-m-high marine terrace at the Vostok Inlet coast. This episode of relative cooling resulted in a slightly wider distribution of larch and alder forests in the coastal plain. Areas located closer to piedmonts were overgrown with birch–broad-leaved forests. The average annual temperature was by 2°C lower than now, and July and January were by 1–2°C cooler than at present; precipitation was at the same level (Table).

The subhorizon **SBO_2** is represented by gray, moderately sorted (0.23) silts (Hole 132, depth interval of 0.5–2.7 m). The heavy fraction is terrigenous in composition, dominated by rock clasts and hornblende. Composition of terrigenous minerals from the SBO_1 and SBO_2 subhorizons is similar. The diatom assemblage shows noticeable changes: the proportion of marine and brackish-water diatoms increases from 54 to 85%, whereas that of freshwater species decreases to 19%. The taxonomic composition of marine diatoms also changes: oceanic diatoms *Coscinodiscus oculus-iridis* and *C. marginatus* appear at this level and coexist with neritic (*Porosira glacialis, Thalassiosira nordenskioldii, Actinoptichus undulatus*) and sublittoral (*Cocconeis scutellum, Navicula forcipata, N. transitans*) species. These changes in the diatom assemblage imply the further sea-level rise. The foraminiferal assemblage also changes, and species *Eggerella advena, Trochammina inflata,* and *Elphidium subclavatum* become preponderant. The Subboreal molluscan assemblage (SBO_2) is discovered in the silt member within the depth interval 1.4–2.7 m of Hole 132. Its age determined by the ^{14}C method is 3530 ± 130 years (MSU-858). Shells are well preserved. The sediments represent most likely a typical facies of autochthonous sedimentation at the water depth of about 20 m (Evseev, 1981). The molluscan assemblage is cold-resistant, including abundant boreal–arctic species *Liocyma fluctuosa, Macoma calcarea, Serripes groenlandicus,* and widespread boreal species *Protothaca staminea.* Such a combination of species reflects the regular vertical zoning in distribution of mollusks belonging to different zoogeographic groups. Thus, the sea-level position and climate in the second half of the Subboreal period were similar to the modern ones.

The terminal Subboreal time corresponds to the climate warming. In the palynological spectra, the content of arboreal pollen increases to 72% mostly due to the growing abundance of *Pinus koraiensis* (to 30%). At the same time, the share of broad-leaved thermophilic elements (to 34%) and general taxonomic diversity of plants are reduced as compared with the Atlantic optimum. The same spectra are characteristic of muddy sediments at the base of the 2.5-m-high terrace of the Kievka River. Landscapes of that time were occupied by coniferous–broad-leaved forests dominated by *Quercus, Picea, Pinus koraiensis,* and subordinate *Betula.* The average annual, summer (July), and winter (January) temperatures were by 1–2°C higher as compared with these parameters at present (Table).

In the section of the 4-m-high terrace at the Vostok Inlet, the above-described basal sediments of the Atlantic age are overlain by a member of compact, moderately sorted (0.29) silt. Terrigenous minerals of the heavy fraction are amphiboles, epidote, ilmenite, and

others. Authigenic components are largely represented by Fe sulfides. The results of palynological analysis indicate that a slight cooling resulted in appearance of forests consisting of small- and broad-leaved taxa. The cooling corresponding to the first half of the Subboreal period was associated with a slight sea-level fall and formation of lagoon. The silty member is overlain by bedded well-sorted (0.43) sand. The heavy fraction of sand shows a high content of pyroxenes (to 44%), rock clasts (to 30%), and garnet (to 51%). According to palynological data, the member was formed under conditions of climatic amelioration in the second half of the Subboreal period, when widespread were cedar–oak forests.

The Subboreal period is marked by a series of events. Its beginning corresponds to an insignificant sea regression. Lithology of shelf sediments and taxonomic composition of diatom, molluscan, and foraminiferal assemblages imply that sedimentation in a shallow-water setting developed under climatic cooling. Areas adjacent to the sea turned into lagoons full of foodstuff (fish, birds, animals) and, naturally, attracted ancient man (hunters, fishermen). The sites, which continued to exist on hill slopes, became agricultural areas of permanent settlements. The archeological data confirm the low (regressive) sea-level stand. The ancient man sites appeared on the abrasion surface 4.5 m above the sea level directly after its exposure at the day surface (Selivanov and Stepanov, 1982). The second half of the Subboreal period corresponded to the new phase of sea-level rise and climatic warming. Sediments of this time yield the cold-resistant and relatively deep-dwelling molluscan assemblage; they also show an increased content of marine diatoms, among which the oceanic species appeared. According to archeological data, the ancient man sites of different culture appeared again on the structural–denudation surfaces located 20–40 m above the sea level.

The Subatlantic sediments are recovered in Holes 132, 133, 119, 180, 162, and 163 drilled in the shelf, being exposed as well in the sections of coastal marine terraces. They are represented by sands with pebbles and gravel, by coarse gravel with abundant molluscan shells, and by lagoonal to shallow-water sand and mud beds bearing plant remains and mollusks. Geomorphology of the coast, facies relationships between the shelf and terrace deposits, and archeological data elucidate stages of the coastal-marine sedimentation at that time. The onset of the Subatlantic stage (SAT_1) was a time of climatic cooling. In the palynological spectra, the share of pollen of cold-resistant taxa slightly increases. This relative cooling is particularly expressed in sediments of the first floodplain terrace of the Kievka River. In the maritime plain, the forest formations were replaced by alder groves, and this change in vegetation was probably a response to the partial exsiccation of landscapes. The coastal area of that period hosted sites of the spectacular Yankov Culture of ancient man (the early Iron Age of the Primor'e region); their age is estimated to be 2500–2000 years. Ancient man placed his seasonal sites not only 4–5 m above the sea level, but also near the modern sea level (Melkovodnaya Bay). The sea retreats at that time, and the estimated sea level fall was equal to 2–3 m.

Sediments accumulated during the second half of the Subatlantic period (SAT_2) are characterized by the "moderately warm" palynological spectra with an increased share of arboreal pollen mainly representing the dark coniferous species *Pinus koraiensis* (24–68%). The pollen content of broad-leaved taxa, mostly of *Quercus mongolica*, became slightly reduced (16–36%). The time under consideration was characterized by a significant expansion of dark coniferous formations mainly consisting of *Pinus koraiensis* with an insignificant admixture of broad-leaved species (mostly oak). According to Neishtadt (1957), this time can be designated as the *Pinus koraiensis* phase. The period of the mid-Subatlantic warming corresponds to formation of the 2.5-m-high coastal marine accumulative terrace, whose age is estimated using the radiocarbon analysis of molluscan shells and corresponds to 1420 ± 180 years (MSU-758; Melkovodnaya Bay) or 1400 ± 200 years (MSU-810; Kievka Cove). The mid-Subatlantic warming epoch coincided with transgression of the Sea of Japan. The archeological data indicate that the Yankov Culture sites are buried in beach sand or gravel–pebble sediments of the coastal bars 4.2 m high. Ceramic remains from sites appear to be artificially crushed and rounded, whereas stone tools remained intact. Accordingly, the transgression event was short-term.

At the end of the Subatlantic period (SAT_3), the proportion of dark coniferous pollen in palynological spectra decreases. In the vegetable cover, dark coniferous formations become significantly enriched in broad-leaved and small-leaved species. Climate and vegetation of that time resembled the modern ones. The 4-m-high marine terrace with the well-expressed surface and 18 coastal bars traceable along the distance of 2 km from the shore line of the Kievka Cove continued to be formed at that time. The age of sediments at the depth of 2.2 m below the surface of the fifth bar is 720 ± 150 years (MSU-759). Sediments accumulated at the end of the Subatlantic period are represented by a thin surface layer in all studied boreholes and marine terraces. The molluscan shells from shelf sediments, which are recovered from the depth interval of 0.5–0.8 m in Hole 132, are dated back to 160 ± 110 years ago (MSU-826). The surface layer of shelf sediments contains foraminifers *Eggerella advena, Trochammina inflata*, and others. Calcareous foraminifers are virtually absent, whereas their agglutinated forms are dominant and diverse. These forms are mostly of the shallow-water origin and typical of slightly freshened waters of boreal basins (Troitskaya, 1973). The concurrent diatom assemblage characterizes sedimentation environments similar to modern ones in the shelf areas of the Sea of Japan.

The molluscan assemblage from sediments of the Subatlantic age is identical to that of the second half of the Subboreal period. The respective cold-resistant mollusks (Hole 132) dwelt at the depth of about 20 m, but shoals were occupied by the thermophilic molluscan assemblage, whose representatives occur in sediments of coastal terraces. This peculiar thermophilic assemblage predominantly consisted of low-boreal species *Spisula sachalinensis, Callista brevisiphonata, Mya japonica, Glycymeris yessoensis, Venerupis japonica, Protothaca euglipta*, and others. The same species occur in modern beach sediments.

CONCLUSION

The Holocene sediments thoroughly studied in the shelf drilling sites and in sections of coastal terraces in the Kievka and some other small bays and Vostok Inlet are subdivided into five units correlative with the known stratigraphic subdivisions of the Holocene in southern Primor'e (Korotkii *et al.*, 1976, 1980) and Siberia (Khotinskii, 1977; Kind, 1974). In the depression, the Holocene section begins with sediments accumulated in the Preboreal period and conformably overlying deposits of the cold Sartanian time. These basal Holocene sediments are 9660 ± 160 years old according to results of the radiocarbon dating. Two Holocene levels are most distinct: one corresponding to the beginning of the series (10.3–10.0 ka ago) and another coinciding with the beginning of the Boreal period (about 9 ka ago); both levels mark significant landscape changes. The warming phase at the lower Holocene boundary (10 300–10 000 years ago) is evident from the following features recorded at this level: (1) the cryophilic palynological spectra of the periglacial type are replaced by moderately thermophilic ones; (2) abundance of freshwater diatom species decreased; (3) lithology of sediments and mineral composition of the heavy fraction changed; and (4) geomorphological changes became obvious. The second stratigraphic boundary coincides with the level of about 9000 years, when environmental changes left the following records: (1) the replacement of moderately cold-resistant palynological spectra of the second half of the Preboreal period by more thermophilic spectra of the Boreal time; (2) appearance of dominant marine species in the diatom assemblage; and (3) indications of activated morpho- and lithogenesis that affected sedimentation and geomorphological structure of the bay . We propose to consider the level of 9000 years ago as representing the lower Holocene boundary in the shelf zone of the Primor'e region.

Three thermal maximums corresponding to the Boreal, Atlantic, and Subboreal periods are distinguished in the Holocene. The Boreal maximum represents a substantial paleogeographic episode. However, conditions most favorable for development of vegetation and marine fauna were formed during the Atlantic period. The Holocene optimum triggered an intense marine sedimentation in the shelf and coastal areas and corresponded to the peak of postglacial transgression, when the sea level was by 2–3 m higher than at present. The Subboreal maximum was less distinct in general, but corresponded to the most humid climatic phase during the entire Holocene. The level of the Sea of Japan exceeded the present-day one by 1.5–2.0 m. This was a second substantial sea-level rise in the Holocene that occurred after the Atlantic optimum. The postglacial transgression was irregular. The time interval from the initial Holocene to the first half of the Subboreal period corresponded to the permanent sea-level rise with two pauses in the early Holocene. In the second half of the Subboreal period, the sea level exceeded the modern one. The transgression peak coincided with the terminal Atlantic time (AT_3). During the first half of the Subboreal and initial Subatlantic periods, the sea retreated.

Reviewers M.A. Akhmet'ev and S.A. Laukhin

REFERENCES

Evseev, G.A., *Soobshchestva dvustvorchatykh mollyuskov v poslelednikovykh otlozheniyakh shel'fa Yaponskogo morya* (Postglacial Bivalve Assemblages of the Japan Sea Shelf), Moscow: Nauka, 1981.

Khotinskii, N.A., *Golotsen Severnoi Evrazii* (The Holocene of Northern Eurasia), Moscow: Nauka, 1977.

Khudyakov, G.I., Denisov, E.P., Korotkii, A.M., *et al.*, *Istoriya razvitiya rel'efa Sibiri i Dal'nego Vostoka. Yug Dal'nego Vostoka* (History of Relief Development in Siberia and the Far East: The Southern Far East), Moscow: Nauka, 1972.

Kind, N.V., *Geokhronologiya pozdnego antropogena po izotopnym dannym* (The Late Anthropogene Geochronology Based on Isotopic Data), Moscow: Nauka, 1974.

Korotkii, A.M., Karaulova, L.P., and Troitskaya, T.S., *Chetvertichnye otlozheniya Primor'ya (stratigrafiya i paleogeografiya)* (Quaternary Deposits of the Primor'e: Stratigraphy and Paleogeography), Novosibirsk: Nauka, 1980.

Korotkii, A.M., Troitskaya, T.S., Karaulova, L.P., and Tsar'ko, E.I., Late Oligocene Regression of the Sea of Japan, in *Rel'ef i rykhlye otlozheniya Primor'ya i Priamur'ya* (Relief and Soft Deposits of the Primor'e and Amur River Area), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1976, pp. 117–131.

Kulakov, A.P., *Morfotektonika i paleogeografiya materinskogo poberezh'ya Okhotskogo i Yaponskogo morei v antropogene* (Anthropogene Morphotectonics and Paleogeography of the Coasts around the Seas of Okhotsk and Japan), Moscow: Nauka, 1980.

Kulakov, A.P. and Pushkar', V.S., Continental Coast of the Southern Far East at the Anthropogene Time (Main Evolutionary Trends), in *Rel'ef i rykhlye otlozheniya Primor'ya i Priamur'ya* (Relief and Soft Deposits of the Primor'e and Amur River Area), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1976, pp. 41–62.

Kuz'mina, N.N., Holocene Epoch of the Shelf Evolution in Connection with Working of Building Materials and Construction of the Coast, *Proc. Coastal Zone Conf.*, Halifax, 1994, vol. 4, pp. 1853–1856.

Kuz'mina, N.N., Abstracts of Papers, *XIV Int. INQUA Congress*, Berlin, 1995, p. 151.

Kuz'mina, N.N. and Postolenko, G.A., Chronologically Correlated Sedimentation Processes in the Continental and Shelf Valleys, *Dokl. Ross. Akad. Nauk*, 1995, vol. 345, no. 5, pp. 657–659.

Kuz'mina, N.N. and Shumova, G.M., Environmental Conditions during the Late Pleistocene and Holocene Climatic Optima in the Primor'e Shelf, in *Geokhronologiya chetvertichnogo perioda* (The Quaternary Geochronology), Moscow: Nauka, 1992, pp. 143–153.

Kuz'mina, N.N. and Stepanov, V.P., Some Peculiarities of the Holocene Evolution of the Coastal Zone around the Sea of Japan, in *Chelovek i priroda na Dal'nem Vostoke* (Man and Environment in the Far East), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1984, pp. 19–21.

Kuz'mina, N.N. and Taldenkova, E.E., Abstracts of Papers, *The IGU Conf. on Global Changes and Geography*, Moscow, 1995, p. 203.

Kuz'mina, N.N., Shumova, G.M., Polyakova, E.I., and Nedesheva, G.N., Holocene Paleogeographic Reconstructions for the Northwestern Coast and Shelf of the Sea of Japan, *Izv. Akad. Nauk SSSR, Ser. Geogr.*, 1987, no. 4, pp. 78–89.

Neishtadt, M.I., *Istoriya lesov i paleogeografiya SSSR v golotsene* (Holocene History of Forests and Paleogeography in the USSR), Moscow: Akad. Nauk SSSR, 1957.

Pletnev, S.P., *Stratigrafiya donnykh otlozhenii i paleogeografiya Yaponskogo morya v pozdnechetvertichnoe vremya po planktonnym foraminiferam* (Stratigraphy of Bottom Deposits and Paleogeography of the Sea of Japan in the Late Quaternary: Implications of Planktonic Foraminifer), Vladivostok: Dal'nevost. Nauchn. Tsentr Akad. Nauk SSSR, 1985.

Selivanov, A.O. and Stepanov, V.P., Experience of Coastal Geoarcheological Investigations (the Soviet Primor'e as an Example) in *Izmeneniya urovnya morya* (Sea Level Changes), Moscow: Mosk. Gos. Univ., 1982, pp. 115–133.

Shumova, G.M., Kuz'mina, N.N., and Klimanov, V.A., Holocene Coastal Vegetation and Some Climatic Peculiarities in the Central Primor'e, in *Voprosy obshchei fizicheskoi geografii i paleogeografii pleistotsena* (Problems of General Physical Geography and Pleistocene Paleogeography), Available from VINITI, 1986, no. 3150–8–86, Part 1, pp. 112–120.

Taldenkova, E.E., Fossil and Recent Mollusks of the Coastal and Shelf Sediments, Northwestern Sea of Japan, in *Proc. Coastal Zone Conf.*, Halifax, 1994, vol. 5, pp. 2126–2132.

Troitskaya, T.S., Foraminifers from Shelf of the Western Sea of Japan and Their Life Environment, in *Voprosy biogeografii i ekologii foraminifer* (Problems of Foraminiferal Biogeography and Ecology), Novosibirsk: Nauka, 1973, pp. 119–168.

Stratigraphy and Geological Correlation, Vol. 8, No. 4, 2000, pp. 419–422. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 8, No. 4, 2000, pp. 108–112.
Original Russian Text Copyright © 2000 by V. Negrutsa, Heiskanen, T. Negrutsa, Robonen.
English Translation Copyright © 2000 by MAIK "Nauka/Interperiodica" (Russia).

CHRONICLE

Third Interdepartmental Regional Stratigraphic Meeting on the Lower Precambrian of Karelia and the Kola Peninsula

V. Z. Negrutsa*, K. I. Heiskanen, T. F. Negrutsa*, and V. I. Robonen****

** Geological Institute, the Kola Scientific Center, Russian Academy of Sciences, ul. Fersmana 14, Apatity, 184200 Russia*

*** Geological Institute, the Karelian Scientific Center, Russian Academy of Sciences, ul. Pushkinskaya 11, Petrozavodsk, 185610 Russia*

Received October 28, 1999

Key words: *Stratigraphy, correlation, events, geochronology, Archean, Lower Proterozoic (Karelian), Karelia, Kola Peninsula.*

At the end of the 1970s and beginning in the 1980s, the collection, systematization, and generalization of available data on the Precambrian geology, geophysics, metallogeny and isotopic chronometry of the eastern Baltic Shield were in progress. This information was carefully discussed by specialists from many organizations involved in the geological study of the Kola Peninsula and Karelia. As a result the unified stratigraphic successions of the Archean, Lower and Upper Proterozoic deposits in the study area were elaborated for the first time. In 1982, at the specially convened Interdepartmental Regional Stratigraphic Meeting (IRSM), the stratigraphic schemes were coordinated and adopted (Bogdanov *et al.*, 1983; Kratz *et al.*, 1984). The Archean and Upper Proterozoic schemes were regarded as workable, and that for the Lower Proterozoic was qualified as a correlation scheme. All the schemes were compiled on the basis of the structural and facies zoning in the territory and represented the results of correlation of generalized stratigraphic successions in each of the subzones. All local sequences were established as a result of a detailed geological mapping (1 : 50000 and larger) and were comprehensively detailed in the course of the topical research. The study was carried out by of specialists from PGO "Sevzapgeologiya", All-Russia Institute of Geology (VSEGEI), Karelia and Kola scientific centers, Geological Institute and Far-East Institute of Geology and Geophysics of the Russian Academy of Sciences, St. Petersburg State University, St. Petersburg Geological Institute, and from many other organizations. As a result, an agreement was reached in the understanding of geohistorical essence of concrete stratigraphic subdivisions and their boundaries, and of the boundary positions in the type sections. However, the correlation between sections of isolated tectonic structures remained less definite, and this led to considerable disagreements in understanding of the regional Lower Precambrian stratigraphy and in the isotopic age estimation for the identified subdivisions. The disagreements and a series of attendant circumstances prevented the publication of stratigraphic scales in the form adopted at the meeting of 1982. As a result, the Bureau of the Interdepartmental Stratigraphic Committee confirmed at its meeting in1989 only the resulting left-hand part of the scheme adopted by the IRSM. In 1990, at the All-Union Stratigraphic Meeting in Ufa, the Karelian was divided into two parts in contrast to the adopted scheme. Moreover, in the column "Characteristic regional representatives" only the Vepsian Superhorizon was shown in the Upper Karelian interval.

Later researches and, in particular, the compilation of legends to the new generation of geological maps, were carried out in 1995–1998 by PGO "Sevzapgeologiya" under the guidance of M.A. Korsakova for the Karelian Group, and by PGO "Central Kola Expedition" under the leadership of A.M. Remizova for the Kola series. This work revealed the necessity for a considerable renovation and detailing of stratigraphic schemes adopted by the International Stratigraphic Commission (ISC) in 1989. Accordingly, the stratigraphic base for the new generation of the geological maps scaled 1 : 200000 and 1 : 1000000 must be revised. Authors of the legends verified the Precambrian zoning of Karelia and the Kola Peninsula, substantiated stratotypes for the local stratigraphic subdivisions, revealed and characterized for the first time the type complexes of magmatic rocks in the region, and suggested, with due regard for the new geochronological data, a new solution of the problems concerning subdivision and correlation of pre-Riphean deposits in the region, and a new approach to dating of stratigraphic boundaries. The next IRS Meeting was held on the initiative of the ISC Permanent Commission on Stratigraphy of the Lower Precambrian (V.Z. Negrutsa, Chairman) and of the Regional Interdepartmental Stratigraphic Commission for Northwestern Russia (K.I. Heiskanen, Chairman). The meeting was convened on June 18, 1999, at the time of the International

Conference: "The Precambrian rifting, magmatism, metallogeny. Correlation of geological complexes of Fennoscandia," which was hold in Petrozavodsk at the Institute of Geology of the Karelian Scientific Center, Russian Academy of Sciences. The conference and IRSM was attended by specialists on the Precambrian of the Baltic Shield and on the structural petrology and geochronology that was favorable for comprehensive discussions of Precambrian stratigraphy and latest achievements in correlation of exogenic and endogenic events in the region. In the preparation and proceedings of the IRSM, the active participation of the Petrographic Council for Northwestern Russia (V.S. Kulikov, Chairman), under auspices of which the conference took place, was of essential importance. The IRSM was attended by 35 participants from ten geological organizations of Moscow, St. Petersburg, Petrozavodsk, Apatity, Monchegorsk, and Arkhangel'sk.

On May 12, 1999, in the course of preparation for the IRSM, a workshop was convened in Petrozavodsk under the chairmanship of V.Z. Negrutsa and Heiskanen, and with participation of Yu.B. Bogdanov, A.I. Golubev, V.Ya. Gor'kovets, M.A. Korsakova, V.S. Kulikov, A.M. Remizova, V.I. Robonen, and S.I Rybakov. The workshop considered information by Korsakova and Remizova about the results of their work on legends to the new generation of geological maps (scale 1 : 200000), compared these legends with the already known pre-Riphean subdivision scheme for the Baltic Shield, and discussed factual evidences elucidating structures, composition, and isotope ages of the Lower Precambrian formations in the region. The model of elaborated stratigraphic scheme for Karelia and the Kola Peninsula was suggested for discussion by the IRSM. The workshop program reserved time for questions and suggestions in the course of presentations.

In his introductory speech at the IRSM of 1999, N.Z. Negrutsa recalled the history of two preceding meetings on the Precambrian in the eastern Baltic Shield and the documents adopted at these meetings. He also drew particular attention to the general significance of Proterozoic (pre-Riphean) stratigraphy in the Karelia-Kola region and formulated major tasks of the meeting that was aimed to correlate the regional stratigraphic schemes at the modern level of achievements in stratigraphy of the region, to set up the new basis for the legends of the State Geological maps of the new generation, and to improve understanding of the Precambrian history of the complicated regional structure. Presentations by Korsakova and Remizova dealt with specifics of work on elucidating the Early Precambrian periodic stratigraphic and petrological events in Karelia and the Kola Peninsula. Korsakova emphasized the necessity for preparation of a new legend for concrete structural–facies zones and the obligatory identification of stratotypes for each of the chronostratigraphic units, which were classed as valid (published), conditionally valid (described in unpublished reports), and non-valid. The IRSM participants supported the new proposal to introduce the magmatic complexes into the stratigraphic sequences and to identify their typical representatives (petrotypes). A similar approach was used by Remizova in compilation of the legend to a series of maps of the Kola Peninsula. She pointed to the essential contribution of the Geological Institute of the Kola Scientific Center, RAS, to the data base comprising the results of isotopic rock dating, and also to the necessity of considering the effect of superimposed process in the legend and to substantiated subdivision of the Lopian into three equal parts. Kulikov and Smol'kin informed the meeting about their work carried out in close cooperation with specialists from the Institute of Geology of the Karelian Scientific Center and from the Geological Institute of the Kola Scientific Center, RAS. The work was aimed to evaluate validity of the Archean and Lower Proterozoic magmatic and metamorphic assemblages of Karelia and the Kola Peninsula, which were described in publications. Only 45 of 137 petrotypes distinguished in Karelia are proved to be valid and 27 conditionally valid; others are characterized as requiring a further revision. Moreover, Kulikov and Smol'kin drew particular attention to the fact that the separation of the intrusive complexes from comagmatic volcanics, as it is adopted in contemporary legends, is not justified in the chronostratigraphic aspect. They also stated that all magmatic rocks should be united into volcano-plutonic complexes, since 90% of the data base dealing with results of isotopic dating consist of chronological data on intrusions. Bogdanov discussed some difficulties related to application of the adopted stratigraphic scheme by geological mapping at the scale 1:1 000 000 and the corresponding necessity for certain changes, in particular, for the grouping of extremely detailed stratigraphic and petrological units into subdivisions of a higher rank.

Robonen (with comments by V.Z. Negrutsa and K.I. Heiskanen) presented the model stratigraphic scheme suggested by the working group and a draft of the explanatory note to it composed by V.Z. Negrutsa. After discussion, the scheme(see Table) was adopted by the meeting. Robonen also discussed the historical–geological criteria used for substantiation of stratigraphic subdivisions, different ranks of subdivisions in the hierarchical subjugation, and boundary ages. He paid particular attention to the multivariant event interpretation of results of the isotopic chronometry and the consequent complicity of their chronostratigraphic application. He also emphasized the principal mew moments used in the suggested scheme: (1) all subdivisions are fixed here by concrete reference sections and, partly, by the boundary stratotypes and points; (2) every subdivision is, in its essence, a unique succession of beds reflecting geological event and differing from surrounding rocks by a set of features enabling recognition and mapping of the unit. Isotopic ages of rocks are considered as supplementary to the historical–geological criteria and useful for the interregional correlation as

Adopted at the session of the Interdepartmental Regional Stratigraphic Meeting on the Lower Proterozoic and Archean Stratigraphy (Petrozavodsk, June 18, 1999)

General (I-II) and regional (III-VI) subdivisions*						Age, Ma	Type sections and stratigraphic units	General time scale**			
I	II	III	IV	V	VI			Age, Ma	Period	Era	Eon
Proterozoic	Upper Pr_2	Riphean R	Burzyanian	Hoglandian HG		1650	Hogland I. succession	1600	Staterian	Paleoproterozoic	Proterozoic
	Lower PR_1	Karelian K	Upper K_3	Vepsian K_3^2 (VP)		1800	Shoksha Formation	1800	Orozirian		
				Kalevian K_3^1 (KL)		1950	Ladoga Group				
			Middle K_2	Ludicovian K_2^2 (LD)	Suisar Su		Suisar Formation	2050	Ryasian		
					Zaonezhie Zn	2100	Zaonezhie Formation				
				Jatulian K_2^1 (JT)	Tulomozero Tm		Tulomozero Formation				
					Medvezhiegorsk Md		Medvezhiegorsk Formation				
					Jangozero Jn		Jangozero Formation				
			Lower K_1	Sariolian K_1^2 (SR)		2300	Seletsk (Luzhma River) and Krasnorechensk successions	2300	Siderian		
				Sumian K_1^1 (SM)		2450	Ozhijarvi–Shombozero and Paiozero successions	2500	Neo-Archean		Archean
Archean	Upper A_2	Lopian L	Upper L_2			2600	Gimola Group	2800	Mesoarchean		
			Lower L_1			2800	Kontok Group	3200	Paleoarchean		
	Lower A_1	Saamian S				3200	Vodlozero Block, PMC***	3600	Eoarchean		
							Volotsk succession				

* Ranks of stratigraphic subdivision: acrotheme (I) and eonotheme (II) of the general scale, complex (III), subcomplex (IV), superhorizon (V), and horizon (VI) of the regional scale.

** The scale of the International Subcommission on Precambrian Stratigraphy.

*** Plutonic–metamorphic complex (PMC).

chronometric markers, the actual age of which may change with growing precision of dating methods.

Every presentation was followed by numerous questions and brief comments also touching upon problems not strictly associated with the stratigraphy of the region, but still interesting in the general sense. In particular, V.V. Zhdanov mentioned the importance of including into the legend and into the Petrographic Code of such cartographic objects as the metamorphic–metasomatic bodies. F.P. Mitrofanov argued against this suggestion. Participants, who discussed in detail the suggested scheme were Bogdanov, Glebovitskii, Korsakova, Kulikov, Lazarev, Mitrofanov, Nalivkina, V.Z. Negrutsa, T.F. Negrutsa, Smol'kin, Remizova, Robonen, Rybakov, Heiskanen, and Shul'diner. The main controversies concerned the Archean subdivisions, for instance, the principles of distinguishing the Saamian and Lopian and the boundary between them, and also the stratigraphic essence of the Svecofennian and its relationships with the Kalevian, Vepsian, and Jatulian. Participants also discussed the following points: the alternative Karelian subdivision into three or two subunits; boundary levels between the Lower and Upper Karelian, or between the Lower, Middle and Upper Karelian; the formal determination of the Sumian base as a base of the Proterozoic; ranks of several boundaries (in particular, between the Sariolian and Jatulian, and also between the Kalevian and neighbor-

ing rocks); the hierarchy of stratigraphic units and their correspondence to the stratigraphic categories of the general stratigraphic scale.

Bogdanov was delegated by a group of specialists from the VSEGEI (A.M. Akhmedov, B.V. Petrov, L.V. Travin, and Shul'diner) to present an alternative variant of the scheme, in which they suggested to divide the Karelian into two subunits with the boundary between the Upper and Lower Karelian at the base of the Jatulian (2300 Ma); the lower Lopian boundary was placed in this scheme at the level of 3100 Ma, and the Archean–Proterozoic (lower Sumian) boundary at the level of 2500 Ma. According to this group of scientists, the Jatulian should be divided into the Yangozero and Tulomozero horizons, the Ludicovian Superhorizon should not be subdivided, and stratotype regions should be indicated instead the type sections and unit stratotypes.

Kulikov reported on the formation periods of subdivisions and on their hierarchy. He also suggested to consider the plutonic–metamorphic rock association of the Vodlozero block as the Saamian type section. As regards geochronology in general, he called upon participants to use the Galactic time scale. Nalivkina paid particular attention to the fact that the level of 2600 Ma determined by isotopic dating for the Archean–Proterozoic boundary correlates well with the actual geological relationships in many sections of the world. Bogdanov pointed out the necessity of verifying the date of 2620 Ma obtained by him and O.A. Levchenkov for volcanics of the Tungud Formation that is attributed to the Sumian, but separated, as he reported, by conglomerates from the overlying acid volcanics, which are undoubtedly Sumian in age. T.F. Negrutsa pointed out that the stratigraphic position of the Tungud volcanites is strictly defined, as they overlie with gradual transition the monomineral quartz deposits of the Okunev Formation and are genetically interrelated with the overlying acid volcanics of the Sumian Ozhijarvi Formation. All these rocks represent a single sedimentary–magmatic cycle, which actually determines the range of the Sumian. Smol'kin, with reference to the discussion about the isotopic age of the Archean–Proterozoic boundary, listed the following dates: 2590 Ma for the Silinjarvi carbonates, 2539 Ma for the Lapponian amphibolites, 2526 Ma for the Rookiaapa volcanics, 2520 Ma for the Vochelambina rhyolites. He also mentioned that the Rb–Sr and Sm–Nd dates are older than 2500 Ma for many rock associations from this stratigraphic level and supported the opinion that the Archean–Proterozoic boundary should be dated back to 2500 Ma. Lazarev remarked, that the date 1950 Ma does not correspond to the real age of the Ludicovian–Karelian boundary. Glebovitskii referred to the world statistics of geochronological dates, which he interpreted as the basis for the Archean subdivision into three parts with the boundaries dated back to 3500 and 3200 Ma. The Archean–Proterozoic boundary position is not so clear, and its isotopic age, as Glebovitskii claims, should be determined methodically before the formal adoption. The Svecofennian, as he believes, is a tectonic term. The earliest development of the Svecofennian structures coincides with the formation of the Ermua ophiolite assemblage and with the opening of the Ludicovian ocean. Rybakov considers that the base of the Svecofennian should be defined as corresponding to the Partanen conglomerates, whereas the Ermua–Outokumpu complex should be attributed to the Ludicovian and taken for the subdivision of an older but not the Kalevian level.

After debates, the IRSM adopted the correlation potential of the recommended stratigraphic scheme (table). The resolution of the meeting particularly emphasized the necessity of elaboration and official adoption of a unified system of type sections and boundary stratotypes and points (standards) for different-rank regional stratigraphic subdivisions of Karelia. It was also stressed that the data list including the valid and coordinated dating results for stratigraphic datums is urgently needed as an imperative prerequisite to the qualitative improvement of the stratigraphic basis for all kinds of industrial activities and geological research in the region. The following objectives were considered to be of primary importance: (a) the revision of criteria for distinguishing the Saamian and for determination of the lower and upper boundaries of the Lopian; (b) the verified subdivision of the Lopian with the regional analysis of the recognized subunits, whose boundaries should be characterized by the isotopic age determinations; (c) the reassessment of the Sumian and Sariolian inner structure and revision of stratigraphic positions of layered intrusions attributed to both periods; (d) the further analysis of the event essence of stratigraphic boundaries and evaluation of hiatus ranges in stratigraphic successions with particular attention to the time span and conditions of structural and paleogeographic changes that closed the Belomorian and opened the Svecofennian basins of sedimentation.

The meeting called attention of the Geological Committee and of other interested bodies to the fundamental importance of stratigraphic achievements not only for geological cartography, but also for metallogenic prognosis and preparation of geological-economic maps. Accordingly, the IRSM proceedings and decisions should be widely distributed and issued altogether as soon as possible.

Reviewer M.A. Semikhatov

REFERENCES

Bogdanov, Yu.B., Negrutsa, V.Z., and Negrutsa, T.F., International Conference on Precambrian Stratigraphy in the Soviet Part of the Baltic Shield, *Sov. Geol.*, 1983, no. 11, pp. 122–124.

Kratz, K.O., Negrutsa, V.Z., Sokolov, V.A., *et al.*, New Data on Stratigraphy: the Soviet Part of the Baltic Shield, *Sov. Geol.*, 1984, no. 7, pp. 102–118.

Translated and Published by **International Academic Publishing Company "Nauka/Interperiodica"**
Distributed Worldwide by **Kluwer Academic/Plenum Publishers**

Lithology and Mineral Resources

Editor-in-Chief
Vladimir N. Kholodov
Member of the Russian Academy of Sciences, Doctor of Geology and Mineralogy

SCOPE

Lithology and Mineral Resources (Litologiya i Poleznye Iskopaemye) reviews a wide range of problems related to the formation of sedimentary rocks and ores. Special attention is devoted to comparison of ancient sedimentary rock- and ore formation with present-day processes, as the idea of actualism has always constituted one of the bases of the scientific philosophy of lithologists. A major part of the journal is devoted to comparative analysis of sedimentary processes on continents and in oceans, as well as the genetic aspects of the formation of sedimentary and hydrothermal-sedimentary mineral resources. The journal was founded in 1963 by Academician N. M. Strakhov. It will be of interest to lithologists, petrographers, geochemists, mineralogists, ore geologists and metallogenists, as well as to other geologists, ecologists, researchers of experimental and analytical laboratories, and graduate students.

Lithology and Mineral Resources is abstracted or indexed in *Chemical Abstracts, Engineering Index,* and *Metal Abstracts Index*

Subscription Rates
2000 Volume 35 • 6 issues • ISSN 0024-4902
$1950 US, $2280 Rest of World

Subscription Office: Kluwer Academic/Plenum Publishers, 233 Spring Street, New York, NY 10013
Phone: (212) 620-8467; Fax: (212) 807-1047; E-mail; journals@plenum.com

Translated by **Institute of Marine Biology**
Published by **MAIK "Nauka/Interperiodica"**
Distributed Worldwide by **Kluwer Academic/Plenum Publishers**

Russian Journal of Marine Biology

Editor-in-Chief
Vladimir I. Kasyanov
Member of the Russian Academy of Sciences

SCOPE:

The *Russian Journal of Marine Biology* covers a wide range of research and some applied aspects of marine biology as a synthetic science related to various fields of study on marine biota and environment. It presents fundamental research on biological processes at molecular, cell, organism, and population levels in marine organisms. Consideration is given to marine objects as models in life sciences. The journal also publishes papers dedicated to events in Russian and international marine science and the history of biology. It is intended for scientists and specialists at research institutes, universities, and other educational establishments; and for those working at laboratories in fisheries and aquaculture.

Russian Journal of Marine Biology is abstracted and/or indexed in *Oceanic Abstracts, Biological Abstracts, Geo Abstracts, International Abstracts of Biological Sciences, Medicinal and Aromatic Plants Abstracts, Ecology Abstracts,* and *Aquatic Science and Fisheries Abstracts,* and is included and cited in *EMBASE, BIOBASE,* and *Current Awareness in Biological Sciences.*

.Subscription Rates
2000 Volume 26• 6 issues • ISSN 1063-0740
$1095 US, $1280 Rest of World

Subscription Office: Kluwer Academic/Plenum Publishers, 233 Spring Street, New York, NY 10013
Phone: (212) 620-8467; Fax: (212) 807-1047; E-mail; journals@plenum.com

The International Academic Publishing Company "Nauka/Interperiodica"
announces the results of the 1999 competition for the best articles published in its journals.
Listed below are the authors who won MAIK "Nauka/Interperiodica" prizes for articles in the Earth Sciences:

Grand prize

Yu.M. Pushcharovsky, E.N. Melankholina, A.A. Mossakovsky, D.Yu. Pushcharovsky, and S.V. Ruzhentsev

A series of papers on the Earth's deep tectonics

☆ ***Geotectonics and Doklady Earth Sciences***

Prizes

1. M.A. Semikhatov, M.E. Raaben, V.N. Sergeev, A.F. Veis, and O.V. Artemova

"Biotic Events and Positive δ^{13}Ccarb. Anomaly at 2.3–2.06 Ga"

☆ ***Stratigraphy and Geological Correlation***

2. V.P. Dymnikov

"Predictability of Climatic Changes"

☆ ***Izvestiya, Atmospheric and Oceanic Physics***

3. N.L. Dobretsov

"Systematic Periodicity of Glaucophane Metamorphism: An Illusion or an Important Geologic Regularity"

☆ ***Petrology***

4. A.N. Didenko

A series of papers on the inner structure and evolution of Phanerozoic oceanic basins

☆ ***Izvestiya, Physics of the Solid Earth***

5. M.N. Koshlyakov, T.G. Sazhina, A.Yu. Gol'din, A.A. Romanov, Yu.A. Romanov, and R.Yu. Tarakanov

A series of papers on problems of climate and water circulation in Pacific Antarctic

☆ ***Oceanology***

6. G.N. Baturin, B.G. Pokrovskii, J. Lucas, and L. Lucas-Prévôt

A series of papers on a wide range of theoretical and experimental problems of phosphogenesis

☆ ***Lithology and Mineral Resources and Doklady Earth Sciences***

7. I.N. Tomson

A series of papers on the metallogeny of Phanerozoic rift zones

☆ ***Geology of Ore Deposits and Doklady Earth Sciences***

8. S.M. Antsyferov, V.K. Debol'skii, R.V. Neimark, N.A. Sezeman, V.F. Brekhovskikh, E.I. Debol'skaya, M.A. Morodasov, E.N. Dolgopolova, A.B. Reshetkov, and A.V. Kotlyakov

A series of papers on the spreading of solutes in water streams

☆ ***Water Resources***

Subscribe to the journals from the Russian Academy of Sciences

Translated and Published by MAIK "Nauka / Interperiodica"
(International Academic Publishing Company "Nauka / Interperiodica")
Distributed Worldwide by INTERPERIODICA

Copy this form to mail or fax your order today

	TITLE	Volume	ISSN	ISSUES	RATE IN US DOLLARS US/CAN	RATE IN US DOLLARS INTERNATIONAL	YOUR ORDER
❑	Biophysics	45	0006-3509	6	$2592	$2700	$ _____
❑	Computational Mathematics and Mathematical Physics	40	0965-5425	12	$2310	$2810	$ _____
❑	Doklady Earth Sciences	370-375A	1028-334X	9	$2905	$3340	$ _____
❑	Doklady Mathematics	61-62	1064-5624	6	$1395	$1600	$ _____
❑	Entomological Review	80	0013-8738	9 + 2 Suppl.	$2635	$3030	$ _____
❑	Environmental Geoscience	3	Pending	4	$610	$690	$ _____
❑	Eurasian Soil Science	33	1064-2293	12 + 2 Suppl.	$2390	$2750	$ _____
❑	Geochemistry International	38	0016-7029	12 + 3 Suppl.	$2890	$3320	$ _____
❑	Geology of Ore Deposits	42	1075-7015	6	$980	$1125	$ _____
❑	Geomagnetism and Aeronomy	39	0016-7932	6	$675	$775	$ _____
❑	Geomagnetism and Aeronomy	40	0016-7932	6	$745	$855	$ _____
❑	Geotectonics	34	0016-8521	6	$580	$630	$ _____
❑	Herald of the Russian Academy of Sciences	70	1019-3316	6	$1410	$1790	$ _____
❑	Izvestiya, Atmospheric and Oceanic Physics	36	0001-4338	6	$810	$870	$ _____
❑	Izvestiya, Physics of the Solid Earth	36	1069-3513	12	$850	$940	$ _____
❑	Journal of Communications Technology and Electronics	45	1064-2269	12 + 2 Suppl.	$3115	$3585	$ _____
❑	Journal of Computer and Systems Sciences International	39	1064-2307	6	$2100	$2420	$ _____
❑	Journal of Ichthyology	40	0032-9452	9 + 2 Suppl.	$2265	$2605	$ _____
❑	Laser Physics	10	1054-660X	6	$1130	$1365	$ _____
❑	Oceanology	40	0001-4370	6	$720	$775	$ _____
❑	Paleontological Journal	34	0031-0301	6 + 3 Suppl.	$2075	$2390	$ _____
❑	Pattern Recognition & Image Analysis	10	1054-6618	4	$700	$800	$ _____
❑	Petroleum Chemistry	40	0965-5441	6	$2840	$2950	$ _____
❑	Petrology	8	0869-5911	6	$980	$1125	$ _____
❑	The Physics of Metals and Metallography	89-90	0031-918X	12 + 2 Suppl.	$2770	$3190	$ _____
❑	Physics of Particles and Nuclei	31	1063-7796	6	$1965	$2085	$ _____
❑	Polymer Science. Series A	42	0965-545X	12	$2630	$3030	$ _____
❑	Polymer Science. Series B	42	1560-0904	6	$1000	$1150	$ _____
❑	Polymer Science. Series C	42	Pending	2	$350	$400	$ _____
	Series A + B + C discount 20%				$3180	$3680	$ _____
❑	Proceedings of the Steklov Institute of Mathematics	228-231	0081-5438	4 + 2 Suppl.	$1405	$1620	$ _____
❑	Russian Journal of Inorganic Chemistry	45	0036-0236	12 + 3 Suppl.	$3405	$3915	$ _____
❑	Russian Journal of Mathematical Physics	7	1061-9208	4	$570	$650	$ _____
❑	Russian Journal of Physical Chemistry	74	0036-0244	12 + 3 Suppl.	$3405	$3915	$ _____
❑	Stratigraphy and Geological Correlation	8	0869-5938	6	$980	$1125	$ _____
❑	Studies on Russian Economic Development	11	1075-7007	6	$715	$820	$ _____
❑	Thermal Engineering	47	0040-6015	12	$1530	$1760	$ _____
❑	Thermophysics and Aeromechanics (only distribution)	7	0869-8643	4	$650	$780	$ _____
						TOTAL	_____

❶ Name _____
Institution _____
Address _____
_____ State _____
City _____ Country _____
Zip/Postal Code _____
Telephone (_____)

Delivery is not made until payment is received

To order by phone call **1 800 633-4931**
or (205) 995-1567 outside the US and Canada

❷ ❑ My payment for $_____ is enclosed.
OR
❑ Bill me. My library's purchase order number is _____

❸ Send this order and payment to:
INTERPERIODICA
P.O. Box 1831
Birmingham, AL 35201-1831
Or fax this order form to (205) 995-1588

Order now for immediate delivery. All journals will be published in 2000!

MAIK "Nauka/Interperiodica" Publishing

is pleased to present to the international scientific community simultaneous Russian- and English-language publication of the journals of the Russian Academy of Sciences

International Academic Publishing Company "Nauka/Interperiodica" (MAIK "Nauka/Interperiodica"), in cooperation with the Russian Academy of Sciences, publishes the results of research in all fields of modern science performed by leading scientists and scientific institutions from Russia, the CIS, and other countries. Simultaneous English translation of the journals is provided by Interperiodica Publishing, the translation division of MAIK "Nauka/Interperiodica". Today, scientists around the world have direct access to the most significant Russian research at the time it is first published in Moscow – at the time it is most relevant to the worldwide scientific community. In addition to more timely publication, readers benefit from more precise translations of each journal, provided by a carefully chosen team of scientific translators with direct access to the authors and editors. English versions of the journals published by MAIK "Nauka/Interperiodica" are distributed worldwide by Interperiodica, Kluwer Academic/Plenum Publishers, and the American Institute of Physics.

MAIK "Nauka/Interperiodica" 2000 volumes include the following titles:

- *Biophysics*
- *Computational Mathematics and Mathematical Physics*
- *Doklady Earth Sciences*
- *Doklady Mathematics*
- *Entomological Review*
- *Environmental Geoscience*
- *Eurasian Soil Science*
- *Geochemistry International*
- *Geology of Ore Deposits*
- *Geomagnetism and Aeronomy*
- *Geotectonics*
- *Herald of the Russian Academy of Sciences*
- *Izvestiya, Atmospheric and Oceanic Physics*
- *Izvestiya, Physics of the Solid Earth*
- *Journal of Communications Technology and Electronics*
- *Journal of Computer and Systems Sciences International*
- *Journal of Ichthyology*
- *Journal of Journals*
- *Laser Physics*
- *Oceanology*
- *Paleontological Journal*
- *Pattern Recognition and Image Analysis*
- *Petroleum Chemistry*
- *Petrology*
- *Polymer Science, Series A*
- *Polymer Science, Series B*
- *Polymer Science, Series C*
- *Physics of Particles and Nuclei*
- *Proceedings of the Steklov Institute of Mathematics*
- *Russian Journal of Inorganic Chemistry*
- *Russian Journal of Mathematical Physics*
- *Russian Journal of Physical Chemistry*
- *Stratigraphy and Geological Correlation*
- *Studies on Russian Economic Development*
- *The Physics of Metals and Metallography*
- *Thermal Engineering*
- *Thermophysics and Aeromechanics**

* *Thermophysics and Aeromechanics* is only distributed by MAIK "Nauka/Interperiodica" Publishing

Please direct all inquiries about the above journals to: **INTERPERIODICA**, P.O. Box 1831, Birmingham, AL 35201-1831.
For faster service call toll-free (800) 633-4931 or (205) 995-1567 (outside US and Canada). Fax: (205) 995-1588, E-mail: interperiodica@ebsco.com

- *Applied Biochemistry and Microbiology*
- *Automation and Remote Control*
- *Biochemistry (Moscow)*
- *Biology Bulletin*
- *Colloid Journal*
- *Cosmic Research*
- *Differential Equations*
- *Doklady Biochemistry*
- *Doklady Biological Sciences*
- *Doklady Biophysics*
- *Doklady Botanical Sciences*
- *Doklady Chemical Technology*
- *Doklady Chemistry*
- *Doklady Physical Chemistry*
- *Glass Physics and Chemistry*
- *High Energy Chemistry*
- *High Temperature*
- *Human Physiology*
- *Inorganic Materials*
- *Instruments and Experimental Techniques*
- *Journal of Analytical Chemistry*
- *Journal of Evolutionary Biochemistry and Physiology*
- *Kinetics and Catalysis*
- *Lithology and Mineral Resources*
- *Microbiology*
- *Molecular Biology*
- *Problems of Information Transmission*
- *Programming and Computer Software*
- *Protection of Metals*
- *Radiochemistry*
- *Russian Journal of Applied Chemistry*
- *Russian Journal of Bioorganic Chemistry*
- *Russian Journal of Coordination Chemistry*
- *Russian Journal of Developmental Biology*
- *Russian Journal of Ecology*
- *Russian Journal of Electrochemistry*
- *Russian Journal of General Chemistry*
- *Russian Journal of Genetics*
- *Russian Journal of Marine Biology*
- *Russian Journal of Nondestructive Testing*
- *Russian Journal of Organic Chemistry*
- *Russian Journal of Plant Physiology*
- *Russian Microelectronics*
- *Solar System Research*
- *Theoretical Foundations of Chemical Engineering*
- *Water Resources*

Please direct all inquiries about the above journals to: **Kluwer Academic/Plenum Publishers**, 233 Spring Street, New York, NY 10013. Phone: (212) 620-8467. Fax: (212) 807-1047, E-mail: journals@plenum.com

- *Acoustical Physics*
- *Astronomy Letters*
- *Astronomy Reports*
- *Crystallography Reports*
- *Doklady Physics*
- *JETP Letters*
- *Journal of Experimental and Theoretical Physics*
- *Optics and Spectroscopy**
- *Physics of Atomic Nuclei*
- *Physics of the Solid State*
- *Plasma Physics Reports*
- *Semiconductors*
- *Technical Physics*
- *Technical Physics Letters*

Please direct all inquiries about the above journals to: **American Institute of Physics**, Circulation and Fulfillment Services, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502 USA. Tel. (516) 576-2270, 1-800-344-6902. Fax: (516) 349-9704, E-mail: subs@aip.org

**Optics and Spectroscopy*: Optical Society of America, 2010 Massachusetts Ave., NW, Washington, DC 20036-1023, Attn.: Publications Department. Tel. (202) 223-8130, (800) 582-0416. Fax: (202) 223-1096.

International Academic Publishing Company "Nauka/Interperiodica" (MAIK "Nauka/Interperiodica")
Profsoyuznaya ul., 90, Moscow, 117864, Russia, Phone: 7 (095) 3361600; Fax: 7 (095) 336 0666,
E-mail:compmg@maik.rssi.ru, http://www.maik.rssi.ru